BEFORE THE
COMMISSION ON WATER RESOURCE MANAGEMENT
STATE OF HAWAII

In Re: Chairperson Recommendation)
to Designate the Iao and Waihee Aquifer Systems)
as Ground-Water Management Areas)

IAO AND WAIHEE AQUIFER SYSTEMS
STATE AQUIFER CODES 60102 and 60103
GROUND-WATER MANAGEMENT AREA DESIGNATION
FINDINGS OF FACT

Commission on Water Resource Management
Department of Land and Natural Resources
November 20, 2002

PREFACE

This FINDINGS OF FACT (FOF) has been prepared for the Commission on Water Resource Management (CWRM or Commission) for its consideration in designating the Iao and Waihee Aquifer Systems, State Aquifer Code 60102 and 60103, on the island of Maui as a ground-water management areas under the authority of Chapter 174C, HRS.

From February 1986 to August 1997, various Board of Land and Natural Resources and Commission initiated designation proceedings, investigations, findings of fact, and reports transpired and culminated in the Commission's latest action on August 13, 1997 to **not** designate the Iao Aquifer System. Although not designated, the Commission added the condition that if the 12-month moving average of pumpage from the aquifer ever exceeded 20 million gallons per day (mgd) in the future, the aquifer would automatically be designated. This condition remains active to date.

On July 12, 2001, Maui Meadows Homeowners Association submitted a petition to the Commission requesting designation of the Iao and Waihee Aquifer Systems as ground-water management areas. A copy of the petition is attached in Appendix A. This constitutes the third designation proceeding for the Iao Aquifer System and the first for the Waihee Aquifer System.

This FINDINGS OF FACT summarizes the CWRM staff investigations and research, comments from consultation with the County of Maui, the public's written and oral comments received at the public hearing, and other existing information on file with the Department of Land and Natural Resources.

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EXECUTIVE SUMMARY

In response to a petition to designate the Iao and Waihee Aquifer Systems as ground-water management areas, the Commission on Water Resource Management (CWRM or Commission) approved a continuance of the designation process. This FINDINGS OF FACT is part of the continuation for designation and addresses the current hydrologic conditions, future planned uses, and public interest information as required by the Water Code, §174C HRS, for the CWRM's designation decision-making duty. Under a ground-water management area the CWRM would regulate water withdrawals from the Iao and/or Waihee Aquifer Systems through a water use permit process. This FINDINGS OF FACT is based upon information on file in the Department of Land and Natural Resources, the research of independent investigators, the written and oral comments submitted to the CWRM at the public hearing, and other planning and scientific literature.

Annotated Summary of Water Management Area Designation Process

The process for taking action on a petition to designate a water management area as defined under the Water Code §174C-41, and the dates associated with progress to-date, follows. This information is restated in Section 2 of the report.

(1) *Petition filed with the Commission* (July 12, 2001).

(2) *Consultation with Mayor, County Council, and County Water Board* (August 6, 2001: staff mailed letters to the Mayor, County Council, and the Department of Water Supply for the County of Maui requesting comments to the petition).

(3) *Comments received from Mayor, County Council, and County Water Board*. (On September 10, 2001, the Maui County Council Member, Charmaine Tavares, submitted a letter requesting more information about the Iao Aquifer System. On the same day, Maui County Council Member, Michael Molina, faxed a letter requesting more information about the Iao Aquifer System. On September 11, 2001, the Maui Department of Water Supply (MDWS) faxed their petition comments to the Commission.)

(4) *Chairperson recommends to the Commission to accept (and to continue the designation process) or to reject the petition within 60 days of receipt of the petition* (August 15, 2001: following the Chairperson's recommendation, the Commission extended the 60-day deadline (September 10, 2001) to the November CWRM meeting to give the Maui County agencies more time to review and offer comments on the petition).

(5) *Commission rejects petition or decides to continue designation process*. (On November 14, 2001, the Commission decided to continue the designation process and also reaffirmed the automatic designation of Iao if the 12-month moving average of pumpage exceeds 20 mgd).

(6) *Publication of notice of public hearing* (December 10, 17, & 24).

(7) *Public hearing is held* (January 9, 2002).

(8) *Completion of staff investigation in cooperation with County and Federal agencies* (January through September 2002).

(9) *Completion of draft of findings of fact* (September 2002).

(10) *Consultation with Mayor, County Council, and County Water Board* (September 2002).

(11) *Completion of final findings of fact,* following comments from County.

(12) *Chairperson recommendation for Commission* for or against designation.

(13) *Commission final action within 90-days* of chairperson recommendation in Step 12.

Iao Aquifer System's Current Ground-Water Issues

The Iao Aquifer System, State Aquifer Code 60102, is located in western Maui and includes high-level dike, basal, and caprock ground-water bodies and is hydraulically connected to the Waihee and Waikapu Aquifer Systems. A total of 48 wells, tunnels, and observation holes exist in this aquifer with 75 percent of the pumpage concentrated north of Iao Stream. The current total pumpage from this aquifer is 16± mgd on a 12-month moving average basis. The current CWRM established sustainable yield of the system is 20 million gallons per day (mgd) and is deemed reasonable at this time. Existing water use presently accounts for approximately 80 percent of the system's sustainable yield.

Presently, water-level and chloride analyses reveal that the upper portion of the transition zone is presently rising and at least three Maui Department of Water Supply (MDWS) wells have experienced substantial increases in their chloride concentrations. The mid-point of the transition zone is presently rising at a rate of 4± ft/year while the top of the transition zone is not rising and remains 292 ft below the deepest production well. Staff believes that rising chlorides at individual wells are due more to localized upconing and infrastructure rather than regional degradation of the aquifer.

The MDWS is the primary large existing user of the Iao Aquifer System for municipal uses through its Central Maui Service Area (CMSA). The Iao Aquifer System is the major ground-water source for the CMSA although Waihee Aquifer System wells have recently come online. Long-range future demands to be satisfied through the CMSA may be at least 29.2 mgd. Therefore, authorized planned uses exceed the sustainable yields (Iao 20 mgd and Waihee 8 mgd = 28 mgd) available to the CMSA. Alternative sources in East Maui have been identified to supplement the Central Maui Water System. However, if this long-range additional water development fails to materialize then supply may fall short of meeting the future demand on the CMSA by 1.2 mgd.

Serious disputes between the interested public and the MDWS have been occurring related to the integrity of the aquifer and land use decisions that affect demand on the aquifer. Given the current data, the integrity of the aquifer is acceptable though current infrastructure constraints are limiting the optimal utility of the aquifer. Additionally, the MDWS has adopted the Iao Water Management Rule, §16-9, which identifies management actions to be taken once certain pumpage and chloride limits have been exceeded. However, this rule has not been enforced by MDWS. The CWRM has no jurisdiction on land use approvals that are under the purview of the County of Maui and the State Land Use Commission.

Waihee Aquifer System's Current Ground-Water Issues

The Waihee Aquifer System, State Aquifer Code 60103, is located in western Maui and includes high-level dike and basal ground-water bodies and is hydraulically connected to the Iao and Kahakuloa Aquifer Systems. A total of 15 wells, tunnels, and observation holes exist in this aquifer with the pumpage concentrated south of Makamakaole Stream. The current total pumpage from this aquifer is 5± mgd on a 12-month moving average basis. The current CWRM established sustainable yield of the system is 8 million gallons per day (mgd) and is deemed reasonable at this time. Existing water use presently accounts for approximately 62 percent of the system's sustainable yield.

Unlike Iao, there is no deep monitor well in Waihee to assess the actual behavior of the basal lens and the transition zone. In general, despite lower water levels than Iao, Waihee sources produce water with lower chloride concentrations.

The MDWS is the primary large existing user of the Waihee Aquifer System for municipal uses through its CMSA. The Waihee Aquifer System currently supplies 23 percent of the total demand from the CMSA. Long-range future demands to be satisfied through the CMSA may be at least 29.2 mgd. Therefore, authorized planned uses exceed the sustainable yields (Iao 20 mgd and Waihee 8 mgd = 28 mgd) available to the CMSA. Alternative sources in East Maui have been identified to supplement the CMSA. However, if this long-range additional water development fails to materialize then supply may fall short of meeting the future demand on the CMSA by 1.2 mgd.

Serious disputes between the interested public and the MDWS have been occurring related to the integrity of the aquifer and to land use decisions that affect demand on the aquifer. Given the current data, the integrity of the aquifer is acceptable though current infrastructure constraints are limiting the optimal utility of the aquifer. The CWRM has no jurisdiction on land use approvals that are under the purview of the County of Maui and the State Land Use Commission.

Major Findings

Given the existing hydrologic data, analyses, and future committed withdrawals from the Iao Aquifer System, this report makes the following findings:

1. The sustainable yield of the Iao Aquifer System, independent of the existing well distribution system, is not more than 20 mgd.

2. The sustainable yield of the Waihee Aquifer System, independent of the existing well distribution system, is not more than 8 mgd.

3. MDWS is the sole major user in both the Iao and Waihee Aquifer Systems.

4. Verified small individual users constitute less than 0.5 percent of total pumpage from the Iao and Waihee Aquifer Systems.

5. The current Iao pumpage, based on a 12-month moving average, is 16± mgd, which is 80 percent of Iao's sustainable yield and is mostly concentrated in the northern half of the aquifer.

6. The current Waihee pumpage, based on a 12-month moving average, is 5± mgd, which is 62 percent of Waihee's sustainable yield and is concentrated in the southern third of the aquifer.

7. High-level dike impounded tunnel water flow is not counted against sustainable yield because their net effect is zero on sustainable yield.

8. Both the Iao and Waihee Aquifer Systems have been experiencing significant drought conditions since 1998.

9. Basal water levels in both Iao and Waihee have been generally decreasing until the year 2000 but have stabilized since then.

10. In Iao, the top of the transition zone is not rising while the mid-point continues to rise, resulting in a thinning phenomenon in the upper transition zone.

11. Chloride concentrations have risen significantly and are approaching the EPA guideline of 250 milligrams per liter (mg/L) in three Iao wells (Mokuhau 1 and 3, 5330-09, 11 and Waiehu Heights 1, 5403-01).

12. Long-range authorized planned future demands from community plans and specified in the Maui County Water Use and Development Plan and recent communications with the County of Maui show there may be a 1.2 mgd deficit should other long-range water developments fail to materialize.

13. Criteria 1 and 4 of the 8 ground-water criteria cited in HRS §174C-44 have been met.

Conclusion

Present available data and information support a finding that the first of the two criteria listed below has been met in the Waihee Aquifer System, while both have been met in the Iao Aquifer System. These criteria are:

1. ***[§174C-44(1)]*** *Whether an increase in water use or authorized planned use may cause the maximum rate of withdrawal from the ground-water source to reach ninety percent of the sustainable yield of the proposed water management area;*

2. ***[§174C-44(4)]*** *Whether rates, times, spatial patterns, or depths of existing withdrawals of ground-water are endangering the stability or optimum development of the ground-water body due to upconing or encroachment of salt water;*

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IAO and WAIHEE AQUIFER SYSTEMS GROUND-WATER MANAGEMENT AREAS DESIGNATION FINDINGS OF FACT

1. PURPOSE

This Findings of Fact Report (FOF) has been prepared for the Commission on Water Resource Management (CWRM), in accordance §174C-43 to 46, HRS. This report should facilitate the Commission's decision of designating the Iao and Waihee Aquifer Systems as the IAO AQUIFER SYSTEM GROUND-WATER MANAGEMENT AREA and the WAIHEE AQUIFER SYSTEM GROUND-WATER MANAGEMENT AREA.

2. DESIGNATION BACKGROUND

The State Water Code process for designation is outlined in §174C-41 to 46, HRS. The process and history is summarized in the following sections.

2.1. Written Petition to Designate, (§174C-41(b), HRS)

On July 12, 2001 Maui Meadows Homeowners Association (MMHA) submitted a petition to the CWRM requesting designation of the Iao and Waihee Aquifer Systems as ground-water management areas. A copy of the petition is attached in Appendix A.

2.2. County Consultation (§174C-41(b) , HRS)

On August 6, 2001, staff mailed letters to the Mayor, County Council, and the Maui Department of Water Supply (MDWS), as required by the Code, requesting comments to the petition.

On August 15, 2001, the CWRM extended the 60-day chairperson recommendation for designation deadline (September 10, 2001) to give the various agencies of the County of Maui more time to review and offer comments on the petition. The CWRM specified this extension would be up until the November CWRM meeting.

Responses were submitted as follows: The Mayor (December 10, 2001); MDWS (September 10, 2001); the County Council (December 3, 2001). Both the Mayor and County Council missed the extended deadline. County responses may be found in Appendix B.

2.3. Recommendation for 'Continuance' (§174C-42, HRS)

On November 14, 2001, the CWRM accepted the chairperson's recommendation for designation by approving the continuance of the designation process. This was done to further investigate the hydrologic conditions and notify the County of the seriousness of the situation. The CWRM-approved action may be found in Appendix C.

2.4. Public Hearing (§174C-42, HRS)

After the CWRM decision to accept the petition and continue the designation process a public hearing is required. Notices for the public hearing were published in the Honolulu Star Bulletin and Maui News issues of December 10, 17, 24, 2001. On January 9, 2002, the CWRM held the public hearing on the island of Maui at the Wailuku Community Center to receive public testimony concerning designation of the Iao and Waihee Aquifer Systems. After the close of the public hearing, testimony was accepted until February 8, 2002. Notices and written public hearing testimony can be found in Appendix D.

2.5. Draft Findings of Fact and County Consultation (§174C-43,44,and 46, HRS)

After the public hearing and completion of staff investigations, a draft findings of fact was presented to the CWRM on September 18, 2002. This draft was circulated to the Mayor, County Council, MDWS, and the petitioner for comments. This draft was also posted on the CWRM website for other interested public access.

2.6. Findings of Fact Report (FOF) (§174C-43,44,and 46, HRS)

After the public hearing, completion of staff investigations and a draft of this FOF, and further consultation with the Mayor, County Council, and MDWS (comments found in Appendix E), this is the final FOF prepared in accordance with Water Code. This document presents the findings relative to the eight (8) ground-water designation criteria as specified in §174C-44, HRS.

3. PROPOSED IAO AND WAIHEE AQUIFER SYSTEMS WATER MANAGEMENT AREAS

3.1. Areal Extent

The Iao and Waihee Aquifer Systems are two of four aquifer systems located within the Wailuku Aquifer Sector, Maui. The Iao Aquifer System area is 17.81 mi^2 (11,400 acres) or 33 percent of the total Wailuku Aquifer Sector area of 53.43 mi^2, while the Waihee Aquifer System is 11.87 mi^2 (7600 acres) or 22 percent of the total Wailuku Aquifer Sector area of 53.43 mi^2 (Yuen and Assoc., 1990, p. B-7). The systems' boundaries are shown in Figure 1 and follow the boundaries as defined in the State's Water Resources Protection Plan (WRPP). They have been accepted by the County of Maui in its Maui County Water Use and Development Plan.

A sector is the largest ground-water subdivision within an island. Maui has six sectors. West Maui is divided into the Wailuku and Lahaina Sectors. A sector is defined as a region having hydrogeological similarities, however, its aquifers are not necessarily hydraulically connected (Yuen and Assoc., 1990; Mink and Lau, 1990; Mink and Sumida, 1984).

Aquifer systems are subdivisions within a sector. Aquifer systems within a sector **are hydraulically connected** as is defined by the WRPP. The systems are considered connected despite their water-level differences. For example, within a system, the high-level dike impounded aquifer leaks water into the dike-free basal aquifer (Mink and Sumida, 1984). Likewise, the water-level differences between Iao and Waihee do not mean they are hydrologically independent of each other.

Figures 1 and 2 show the Iao and Waihee Aquifer System boundaries along with all well locations.

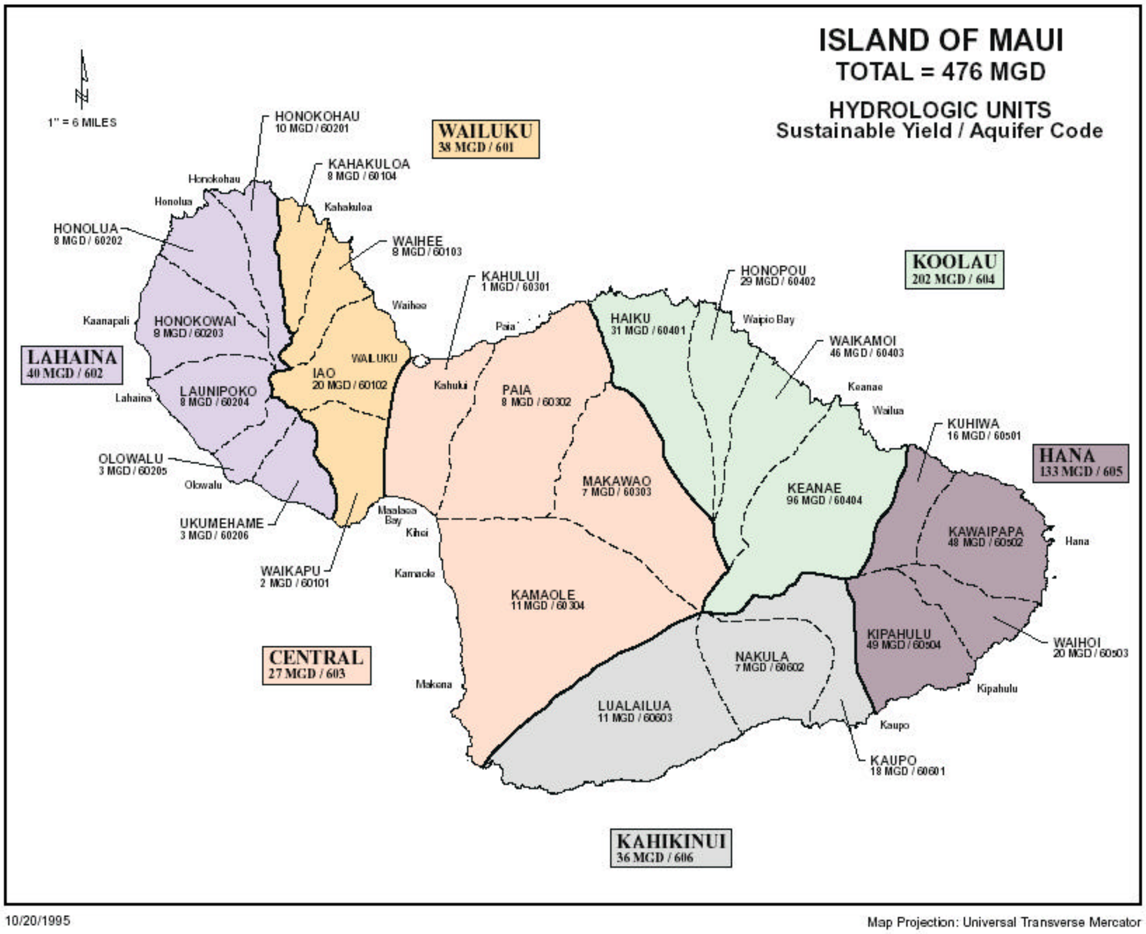

Figure 1. Location of Iao and Waihee Aquifer Systems – Maui

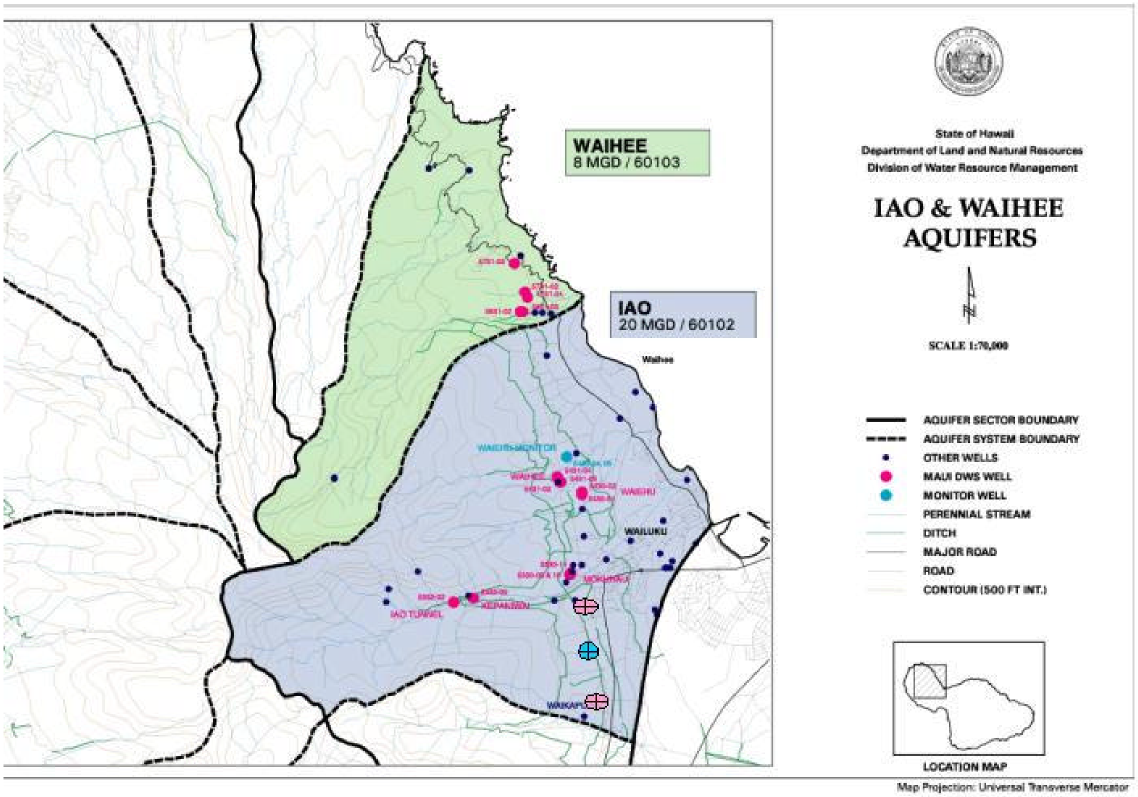

Figure 2. Map of Iao and Waihee Aquifer Systems 11/7/01 map- Maui

3.2. Geology of the Iao and Waihee Aquifer Systems

Figure 3 is the most current geologic map of West Maui (Meyer and Presley, 2001). Thin-bedded, dike-free flows of pahoehoe and aa belonging to the Wailuku Basalt (Langenheim and Clague, 1987) crop out in the ridges behind Wailuku and Waiehu, and represent the shield-building phase of volcanic activity. These flank flows dip steeply away from the caldera region of the volcano. Flow dips range between 10° to 20°(Stearns and Macdonald, 1942), which are somewhat steep for Hawaiian shield-building lava flows. This formation is highly permeable and constitutes the primary aquifer in the system (Stearns and Macdonald, 1942; Yamanaga and Huxel, 1970).

Figure 3. Geology of West Maui.
(modified from Stearns and Macdonald, 1942, and Langenheim and Clague, 1987)

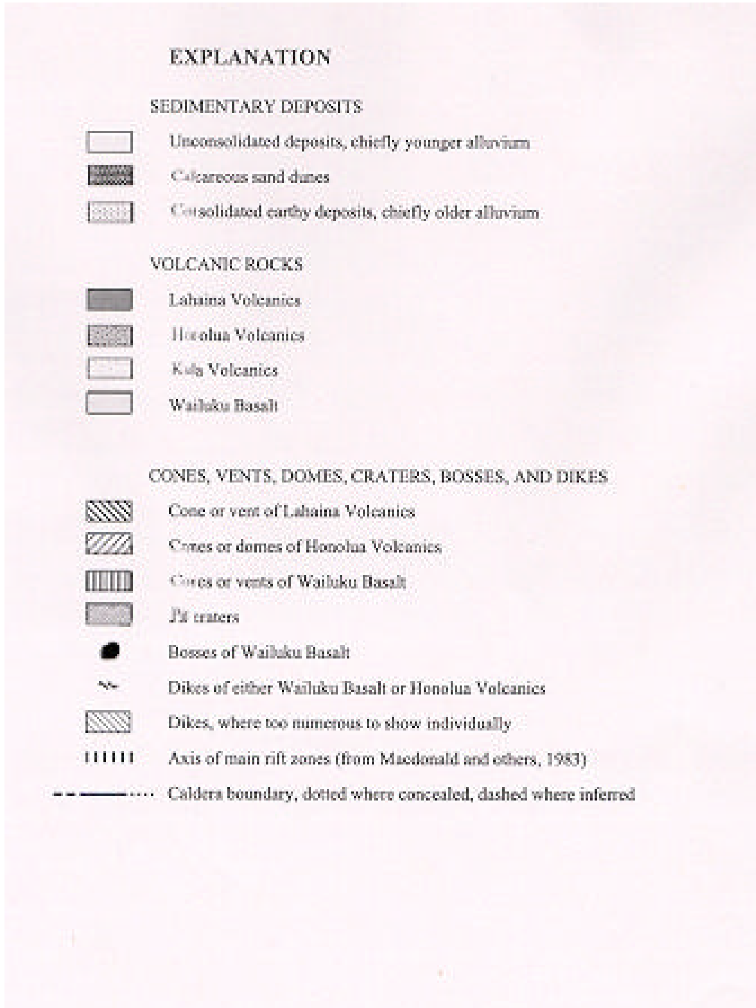

Figure 3 continued. Geology of West Maui.
(modified from Stearns and Macdonald, 1942, and Langenheim and Clague, 1987)

Massive ponded lava flow, dikes, large intrusive bodies, and volcanic breccia associated with the development and filling of West Maui's caldera occur in Iao but not in Waihee. The caldera diameter is estimated to be two miles across is mostly contained in Iao and Waikapu Valleys (Macdonald and others 1983). Runoff is higher in the caldera area because of the lower permeability of the caldera rock. Therefore, there is a higher proportion of runoff to recharge in interior of Iao and Waikapu than in the interior of Waihee.

Stearns and Macdonald (1942) mapped numerous north-striking dikes in Waihee Stream. The trends of these dikes suggest that a volcanic rift zone emanates north from Iao Valley. Their presence, and their influence on the ground-water hydrology, defines the northern boundary of the Iao Aquifer System. Dikes are sub-vertical sheet-like formations that intrude into the existing rock and are of low permeability. The dikes in Waihee are composed of both Wailuku Basalt and Honolua Volcanics. The dike structures impede the flow of water and form the high level aquifer (Macdonald and others, 1983). Dikes have been mapped to within one mile of the coast (Meyer and Presley, 2000; Yamanaga and Huxel, 1970 p. 25).

In the area between Waihee Valley and Wailoi Gulch the Wailuku Basalt is covered by the post-shield stage Honolua Volcanics. This formation is composed of thick bedded and relatively impermeable trachyte and andesite. Mink (1997) suggests that the Honolua Volcanics form a barrier to ground-water flow through the Wailuku Basalt and impedes the outflow of ground water into the ocean. This could account for the relatively high heads in the Waihee Aquifer System basal wells and is different than the alluvial caprock over Iao.

After the eruption of the Honolua Volcanics, the West Maui Volcano underwent an extensive period of erosion. This erosion resulted in a thick sequence of terrestrial sediments known as caprock (Stearns and Macdonald, 1942). These sediments form a wedge that contacts the volcanic rock on the west and thickens to the east. These sediments are composed of young unconsolidated alluvium consisting of sand, silt, and gravel overlying older partly-consolidated to consolidated alluvium. Lithified calcareous dune sand overlies the older alluvium as a thin veneer (Yamanaga and Huxel, 1970). Mink (1977) found based on drill hole data that the Iao caprock wedge extending to a depth of –1200 feet MSL near the coast.

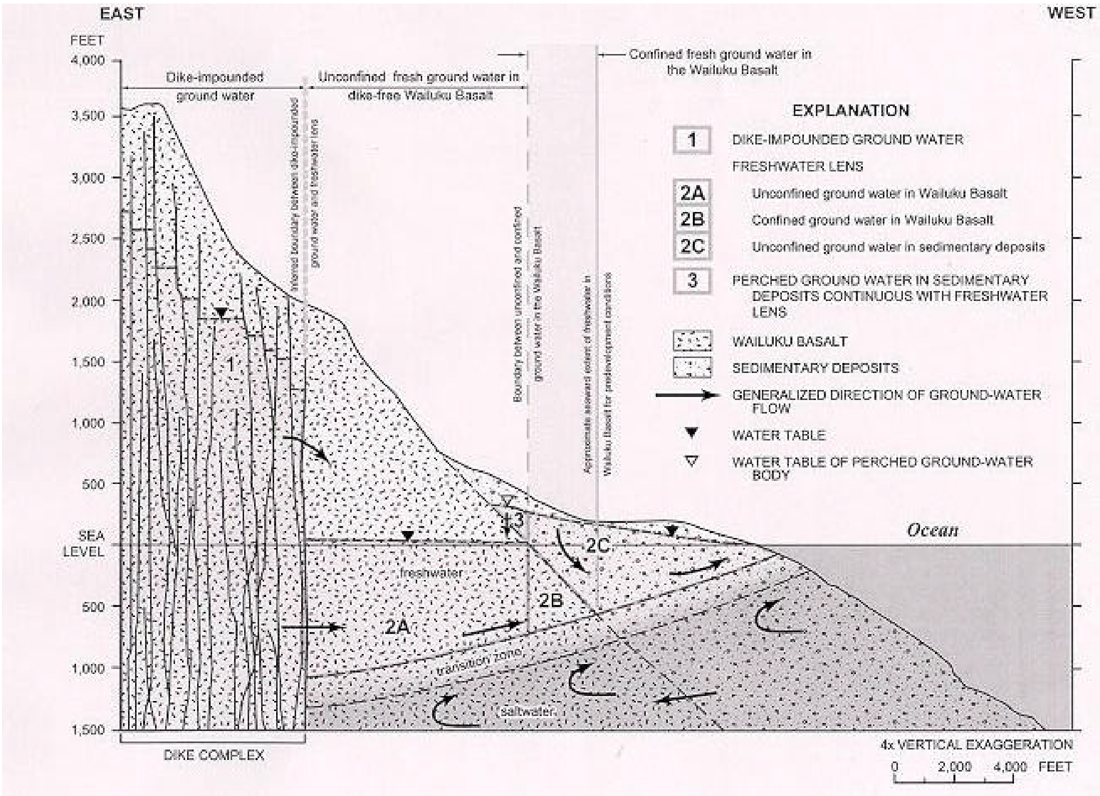

Figure 4. Cross –section of Iao aquifer from Meyer and Presley, 2001.

3.3. Water Balance

A water balance or mass balance is a water accounting method used to estimate aquifer recharge. Figure 5 shows the simplified water budget for an aquifer. For aquifer system recharge the water balance can be characterized with the following parameters: rainfall (P) and fog drip (FD); runoff (RO); evapotranspiration (ET); aquifer inflow/outflow (IO) and aquifer recharge (R). In many aquifers, return-irrigation recharge is also calculated, but currently there is negligible return irrigation in both the Iao and Waihee Aquifer Systems. These parameters are used to form a simple equation:

$$\text{Recharge} = (P + FD) - (ET + RO) = \text{Natural Discharge} + \text{Pumpage}$$

Recharge is equal to total precipitation minus evapotranspiration and runoff. The parameters on the right side of the equation can be measured or estimated in order to calculate a number for recharge.

The results of previous water balances calculated in the West Maui area are presented on Table 2. It is important to note these were calculated for different times (such as when return irrigation was occurring in Iao) and over different areal extents (some including caprock or wider areas). John Mink calculated water balances specifically for the Iao and Waihee Aquifer Systems in the WRPP (Yuen and Assoc., 1990). The other balances are presented for 'approximate' comparison purposes.

A water balance calculation does not account for ground-water flows between aquifer systems. It is very difficult to quantify subterranean flow between aquifers. One would need a calibrated numerical ground-water flow model to address flow issues, but to address recharge within an aquifer system's boundaries a water balance calculation is sufficient. Currently, Geographic Information System (GIS) modeling is the state of the art in computing water balances. GIS water balance calculations have been done for Iao (see Shade, 1997) but not for Waihee.

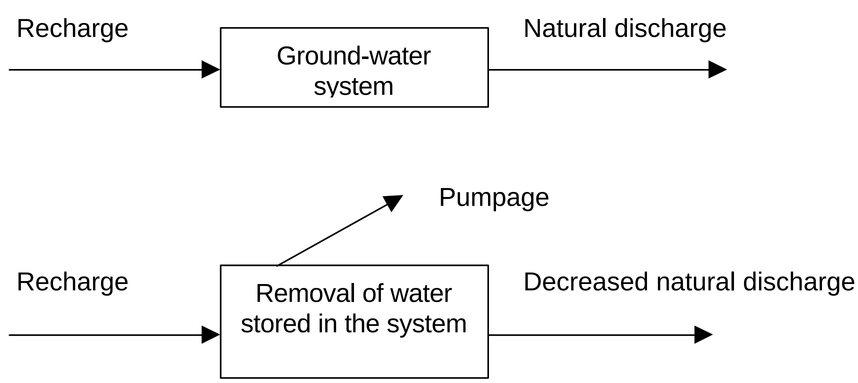

Figure 5. Diagrams illustrating water budgets for a ground-water system for predevelopment and development conditions (adapted from Alley and others, 1999).

A water balance is a good way of looking at a simplified version of the water resources of an area. The following discussion divides the systems' hydrology into the following parameters: rainfall, fog drip, runoff, evapotranspiration and recharge.

3.4. Iao Aquifer System Hydrology

3.4.1. Ground-Water Occurrence

Ground water in the Iao Aquifer System occurs in three areas: 1) upper regional high-level dike confined water, 2) lower regional basal water, and 3) caprock water (see Figure 4, Meyer and Presley, 2001, modified from Mink, 1977) and generally flows from the high-level to the basal to the alluvium caprock and to the ocean. Some ground water also discharges into streams as baseflow. Some Iao ground water may flow into the Waihee Aquifer System through the Waihee River alluvium (Mink, 1997). Potable ground water in the Iao Aquifer System is found in the high-level and basal portions of the system. Non-potable ground water is found in the caprock. The areal boundaries show that the basal source is relatively narrow as imposed by the constraints of the subsurface geology and the location of the high-level dike water boundary. Mink (1977) computed the basal aquifer's initial volume at 220 billion gallons.

3.4.2. Rainfall

The Iao Aquifer System receives a substantial amount of rainfall but with great geographical variation. Mean annual rainfall within the system varies from 20 inches over the noncontributory caprock region near the coast to almost 400 inches at the Puu Kukui summit (Giambelluca and others, 1986). Figure 8 is an isohyetal map of Iao and Waihee. Table 1 lists rain gage stations and corresponding data that occur within the system.

Table 1. Summary of Iao Aquifer System rainfall station data

STATION	NO.	ELEVATION (FT)	MEAN ANNUAL RAIN (IN)	MEDIAN ANNUAL RAIN (IN)	PERIOD OF RECORD
Puu Kukui	380	5788	391.6 380.9	381 NA	R76, p 202 1928-02
Iao Valley Cave	380.1	1720	162	NA	1911-14
Iao Needle	387.2	1250	70	70	1949-77
Iao Valley	387.1	720	67.3	66.8	1949-02

Median rainfall is the 50 percent ranking of rainfall events. It is normally lower than the mass average rainfall given the nature of extreme events such as storms and is more conservative in estimating rainfall. This is evident from the values in Table 1. Although the 50 percent occurrence would seem a more conservative value to use in estimating rainfall, the mass average must be used in water balance calculations that consider mass-balances computations.

Station No. 387.1 in Iao Valley recorded the most continuous daily record of rainfall within the recharge area. Figure 6 shows annual rainfall data at Station No. 387.1 over the entire period of record.

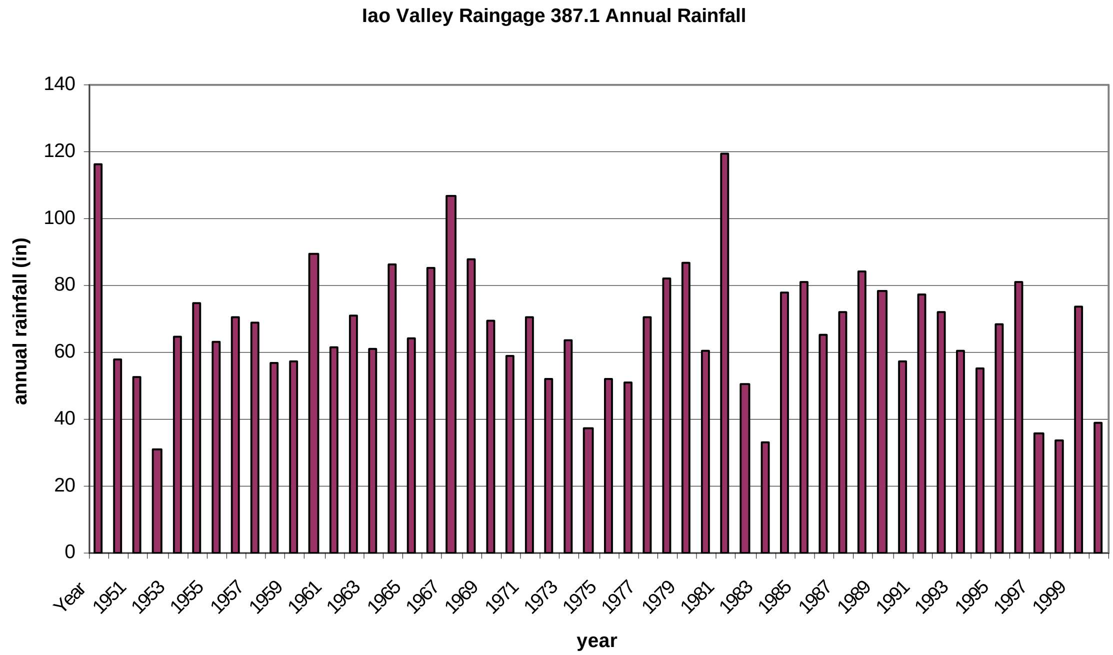

Figure 6. Annual Rainfall at station no. 387.1 in the Iao Aquifer System

Figure 7 illustrates another way of looking at rainfall data from Station No. 387.1. Annual rainfall is taken as a percentage of long-term historical average mean for this gage. Therefore, rainfall percentages greater than 100 percent represent a wet year and rainfall percentages less than 100 percent represent dry years. Over the length of record there have been four major drought periods. The most recent period began in 1998 and continues to the present time, with 2000 being slightly above the mean rainfall.

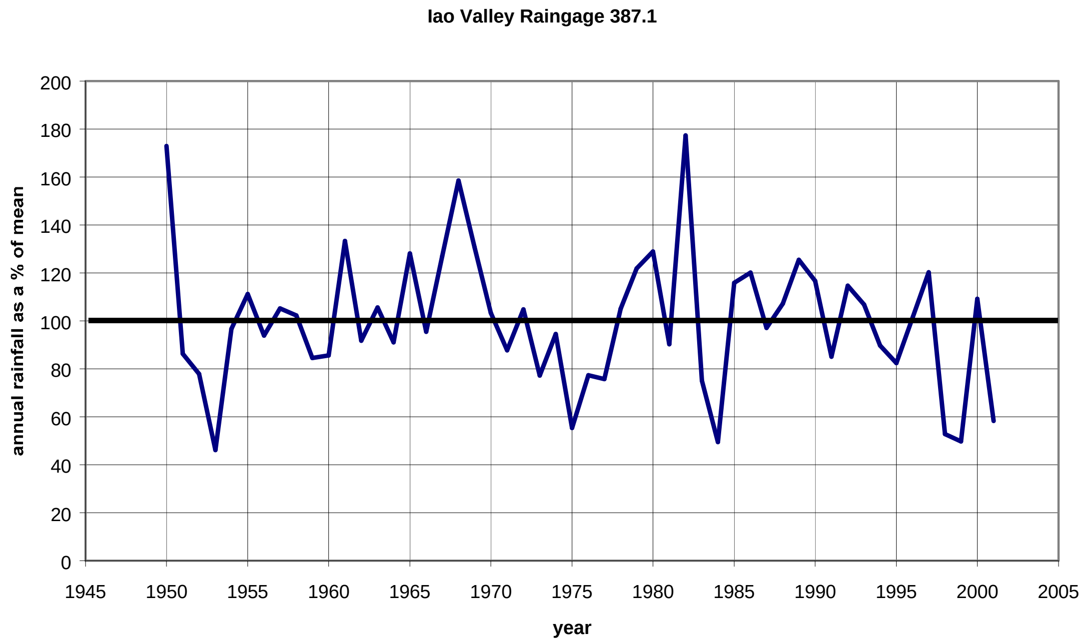

Figure 7. Annual rainfall as a percent of the mean, station no. 387.1 in the Iao Aquifer System.

(Source: Wailuku Agribusiness Rain Gage Reports)

Other stations in Table 1 were read less frequently. Obviously, data for rainfall over the entire system is sparse. However, isohyets can be constructed using existing West Maui rainfall data. Besides areal aquifer location Figure 8 also shows the distribution of mean yearly rainfall over Iao Aquifer System and is consistent with other literature.

Previous reports on Iao rainfall are summarized in Table 2. Table 2 also incorporates other water budget parameters.

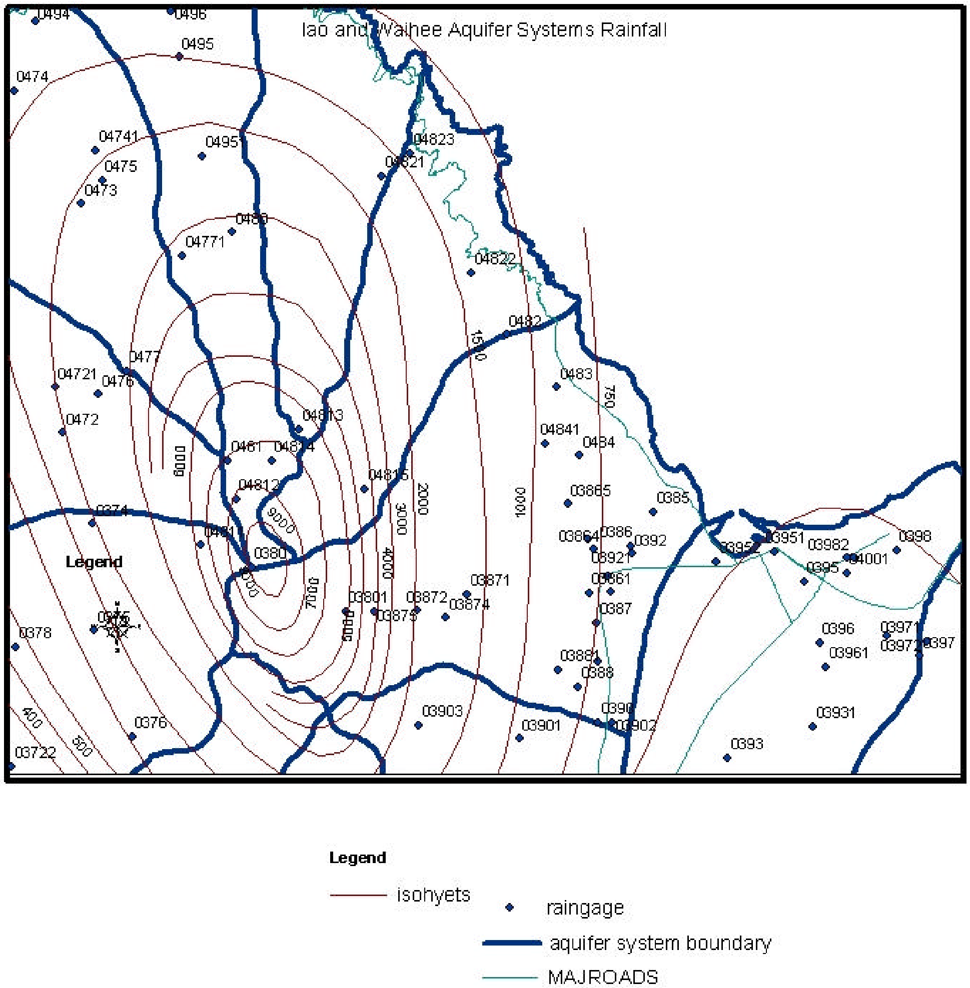

Figure 8. Rainfall map of the Iao and Waihee Aquifer Systems.

Table 2. Iao Aquifer System estimates of hydrologic parameters
Selected water balances for West Maui. Note that these estimates refer to different areas and may not be directly comparable.

Region	Report	Area	Rainfall		Runoff		ET		Recharge			SY
		square miles	mgd	mgd/mi sq	mgd	% of rainfall	mgd	% of rainfall	mgd	% of rainfall	mgd/mi sq	mgd
Iao Aquifer System	WRPP (Yuen and Assoc., 1990)	17.81	82	4.60	33	40%	34	41%	15	18%	0.84	20
Iao Aquifer	Shade (1997)	16.15	87	5.39	40	46%	18	21%	29	33%	1.80	
Lahaina District	Shade (1996) natural cond	96	330	3.44	95	29%	90	27%	145	44%	1.51	
Iao Aquifer System	Mink (1995)	17.81	82	4.60	16.75	20%	34	41%	31.57	39%	1.77	20.2
Iao Aquifer System	USGS (Perry, Maui News, 1992)	17.81										24 to 28
Iao Aquifer System	USGS CWRM presentation (1991)	17.81										20 +
Iao Aquifer System	Mink (1991) appendix to Mink (1977)	17.81							20		1.12	
Wailuku	Takasaki (1978)	NA	370		175	47%	130	35%	65	18%		
Lahaina District	State of Hawaii, 1977 (R54)	60	265	4.42	53	20%	119	45%	93	35%	1.55	
Maalaea to Waihee	State of Hawaii, 1970 (R38)	32.8	230	7.01	120	52%	50	22%	60	26%	1.83	
Iao	State of Hawaii, 1970 (R38)	9.2	95	10.33	50	53%	10	11%	35	37%	3.80	30
northwest Maui (Honokohau to Honokeana)	State of Hawaii, 1969 (R33)	NA	122		40	33%	53	43%	29	24%		
Iao Valley	Caskey (1968)	6.02	83.33	13.84	38.7	46%	12.33	15%	32.3	39%	5.37	
West Maui	Stearns & Macdonald (1942, p 43)	140	580	4.14					145	25%	1.04	
	Average (not weighted)					39%		29%		32%	2.20	

Given the factual data, review of previous investigations, other literature, and staff analysis an estimate for average annual rainfall of 82 mgd is reasonable for the Iao Aquifer System.

3.4.3. Fog Drip

In addition to rainfall, fog drip is probably a significant contributor to the Iao Aquifer System's water resources. Fog drip is the direct interception of water from clouds and fog by condensation on surface areas such as vegetation. Earlier fog drip studies on the islands of Hawaii and Lanai indicate that fog drip is a significant contributor to ground-water recharge on those islands (Anderson, 1984; Ekern, 1964; Mink, 1983).

Earlier estimations of fog drip have not been made for the Iao Aquifer System. Caskey (1968) concluded that fog drip is significant but made no quantitative estimate. Ekern (1978, p.3) notes that at an elevation of about 5,000 feet, fog drip is about 33 percent of rainfall. As the elevation increases above 5,000 feet the proportion of fog drip to rainfall also increases, though total precipitation is substantially less. The elevation of most ridges surrounding Iao Valley and above Waiehu are less than 5,000 feet, though the headwall of Iao Valley rises above 5,000 feet. Therefore, fog drip may be something less than 33 percent of rainfall.

3.4.4. Return Irrigation

Agricultural water use provides a source of additional infiltration water that contributes to the overall ground-water recharge rate. In the past, plantation ditches transported an average of 46 mgd of surface-water from within and outside the Iao Aquifer System boundaries (from the Waihee and Waikapu Aquifer Systems) to irrigate sugarcane within the Iao Aquifer System boundaries. The ditches and their areal relationship with the high-level, basal, and caprock aquifers are shown in Figure 2. Most of the irrigated lands were over the caprock. Presently about 1100 acres are in diversified agriculture and are cultivated over areas that contribute to the basal aquifer recharge through return irrigation. In addition, ditch leakage contributes to the total recharge rate of the basal aquifer. Shade (1997) provides four scenarios for the irrigation component in the water budget done by the USGS. Under Scenario I (natural conditions) there is no irrigation component. Under Scenario II (period from 1926-79) the mean irrigation component was 25 mgd. Under Scenario III (period from 1980-85) when sugar and macadamia nuts were irrigated by drip method, the component decreased to 9 mgd. Under Scenario IV (period from 1986-95) when irrigation was reduced to a mean of 3 mgd. The present condition is very low and most likely between Scenarios I and IV. Shade (1997, Table 4) calculated return irrigation recharge under Scenario IV as 2 mgd greater than under natural conditions. CWRM staff estimates the current return irrigation to be less than 3 mgd.

3.4.5. Runoff

Runoff is the average total stream flow for the aquifer system. It includes the direct runoff from rainfall and base-flow runoff derived from dike zone ground water. Runoff is estimated from existing stream flow data in the aquifer system and similar aquifer systems (Yuen and Assoc., 1990).

Runoff occurs from drainage basins that feed Iao, South Waiehu and North Waiehu Streams. Presently, stream gaging in the Iao Aquifer System is limited to only Iao Stream. In the past, the USGS gaged all three streams (Figure 9). Diversion ditches within the Iao and Waiehu drainages were also measured, though ditches diverted water during average to low stream flows (Caskey, 1968).

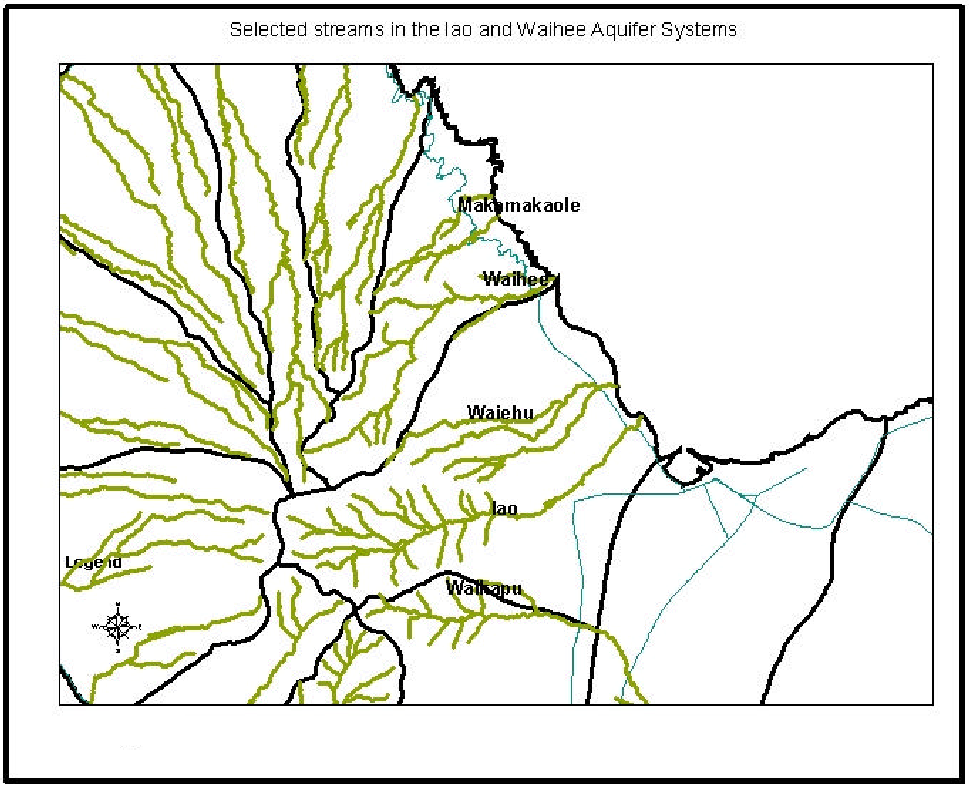

Figure 9. Selected streams in the Iao-Waihee area.

Table 3 summarizes stream discharge data and statistical parameters from various sources (Caskey, 1968; Kunish, and others, 1939; C-61 and R-38, 1970).

Table 3. Iao Aquifer System Stream Gage Discharge Data

GAGE	DRAINAGE AREA (MI^2)	PERIOD OF RECORD	Qave (MGD)	Q50 (MGD)	Q90 (MGD)
Iao Stream	NA	1910-15	51.2[1] 38.7[2]	35.0[1]	13.6[1]
Iao Stream	5.98	1983-00	42.1[5]	26.5[3]	12.9[3]
South Fork Waiehu Stream	0.88	1910-17	7.1[1] 6.4[2] 5[4]	5.1[1]	2.4[1]
North Fork Waiehu Stream	0.90	1910-17	5.5[1] 7.1[2] 5[4]	4.0[1]	2.7[1]

[1]*Kunish & others (1939)*
[2]*Caskey (1968)*
[3]*Matsuoka (Personal Communication, 1991)*
[4]*C-61 and R-38 (1970)*
[5]*U.S.G.S. Water Summary (20000)*

Data presented in Table 3 shows that the short period of record can greatly influence estimations of mean discharge from Iao and Waiehu Streams. The Q50 and Q90 discharges presented by Kunish and others (1939) are interpolated. Caskey (1968) developed his data from correlations with long-term gaging stations. The most reliable data is from Matsuoka (1991) given the recent measurement and longest record.

Other statistical stream characteristics such as Q50 (median flow) and Q90 (base flow) are difficult to resolve for the relatively short-term records that are available. Iwao Matsuoka (personal communication, September, 1991) of the USGS indicated that ideally a minimum of ten years of stream flow record is needed to determine these parameters. He calculated Q50 and Q90 for Iao Stream at Kepaniwai Park (based upon 1983-1991 records for Stream Gage No. 16604500) as 28.4 mgd and 12.9 mgd respectively, while the mean or average discharge at this gage is 43.5 mgd (USGS Water-Data Report HI-00-1, p. 200). Figures 10 and 11 present stream flow data for Iao (1983 to 2000) and South Waiehu Stream (1911 to 1915).

Though stream flow data is limited, previous studies (e.g., Caskey, C-61 and R-38) estimate mean flow through correlation with long-term gaging stations. Stearns and Macdonald (1942) also estimated streamflow. The WRPP gives a mean total Aquifer System runoff quantity in inches per year. The aggregate runoff of the CWRM isohyetal interval analysis along with previous studies estimates are shown in Table 2. CWRM analysis covers the basalt area and includes the caprock area.

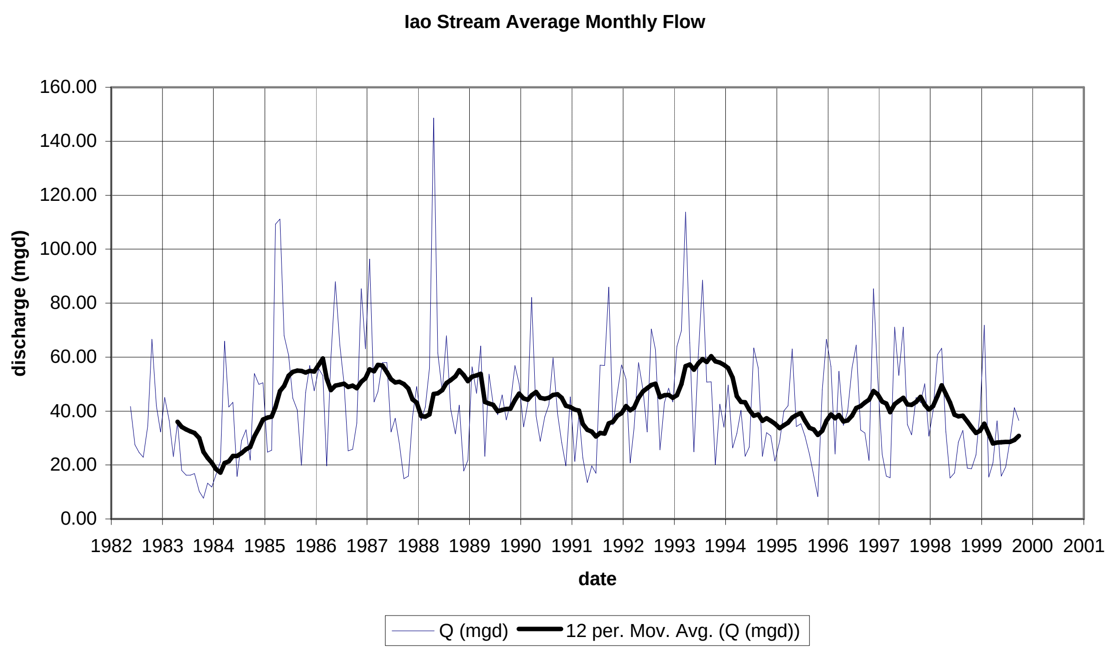

Figure 10. Total historical Iao Stream flow USGS gage 16604500

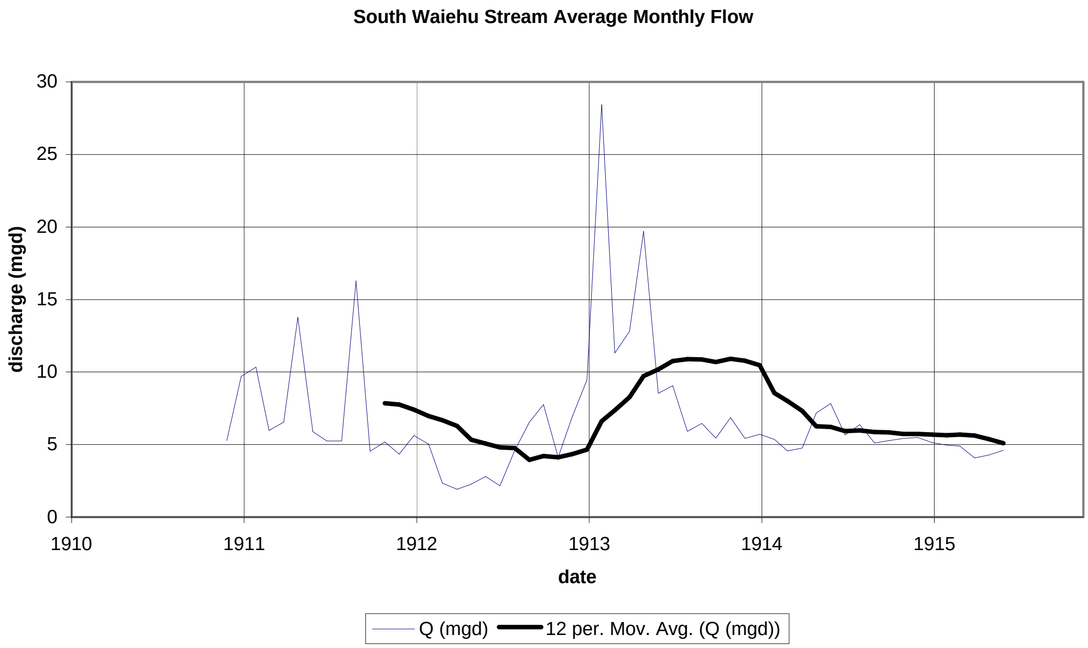

Figure 11. Total historical Waiehu Stream flow USGS gage 16610000

Although the most recent consultant estimate of average runoff for the entire system is 39 in/yr over 17.8 mi^2 or 33 mgd (Yuen and Assoc., 1990), CWRM analysis and past studies suggest a greater amount of runoff is occurring. The CWRM-correlated rainfall and stream flow for Iao Stream over the longest continuous streamflow record, which was a 7-year period, and simulated streamflow based on long-term rainfall data. The resulting runoff for Iao alone constituted 43.5 mgd. Runoff for other areas within the areal extent of the Iao Aquifer was also estimated. Incorporating all runoff estimates for the entire Iao Aquifer System the CWRM estimates an annual runoff of 54.4 mgd. This estimate seems reasonable given the range of previous studies. Shade (1997) estimated direct runoff to be 40 mgd over an area comparable to the basalt portion of Iao, and 41 mgd for direct runoff for the entire area including the caprock portion of the aquifer system.

3.4.6. Evapotranspiration

Evapotranspiration is the surface and subsurface water released to the atmosphere through direct evaporation and by transpiration through plants (Todd, 1980 p 361). Evapotranspiration can be estimated from pan evaporation data. Evapotranspiration has been estimated in previous studies and results are tabulated in the water balance table (Table 2).

Data for evaporation is limited within the Iao Aquifer System. The only reported Iao Aquifer System pan evaporation measurements, found in State Report R74, come from evaporation pan stations, State Key No. 385, near the Wailuku coast. Report R74 shows that adjusted annual evaporation near Kahului is 81 inches per year.

Evapotranspiration due to vegetation depends on plant and climatological factors. For a relative sense, evapotranspiration from a water hungry plant such as sugarcane is estimated by multiplying pan evaporation by a factor that typically ranges from 0.8, for sugarcane in wet areas, to 1.2, sugarcane in very hot and dry areas. Thus, it would be conservative to assume that evapotranspiration equals pan evaporation near the Iao Aquifer System.

The most recent estimate of average evapotranspiration for the entire system is 40 in/yr, or 34 mgd (Yuen, 1990). This is the most conservative value for evapotranspiration, in terms of computing infiltration, compared to other past studies and actual evaporation measurements.

Using the isoheytal interval method the CWRM estimates that evapotranspiration for the entire Iao Aquifer System is 27.1 mgd. This value lies within previous estimates. Given the factual data, review of previous analyses and literature, and CWRM analysis an annual evapotranspiration estimate of 27.1 mgd is reasonable for the Iao Aquifer System.

3.4.7. Ground-Water Recharge

Ground-water recharge is that amount of water, applied in any manner to the ground surface (i.e., natural or irrigation), which infiltrates into and becomes part of the saturated formations of an aquifer. Recharge to the system takes place over the high-level, basal, and caprock aquifers. This report is mainly concerned with recharge to the dike and basal water bodies in the Iao Aquifer System. Recharge to the caprock is negligible, especially to the potable supply and is therefore not considered. In the past, estimates of recharge were taken as conservative percentages of rainfall. Presently, hydrologists use the mass water balance method to estimate ground-water recharge, as illustrated in Figure 5 and summarized in Table 2.

The WRPP (Yuen and Assoc., 1990), estimated mean recharge to be 15 mgd. This official CWRM recharge is averaged over the Iao Aquifer System using water balance algorithms. This estimate of recharge is 19 percent of total rainfall. This is conservative when compared to the average recharge estimate of 33 percent of total rainfall by other researchers (Table 2).

Unofficial updates to the estimate of Iao Aquifer System recharge have been provided since the adoption of the 1990 WRPP. In 1991, Mink (1991, Appendix to 1977 report) revised his assessment of recharge based upon new modeling calculations in conjunction with observations from the Waiehu Deep Monitor Well and concluded that average infiltration lies between 20 and 23 mgd. In a September 9,1995 memorandum to CWRM, Mink again recalculated recharge to be 31.57 mgd. In 1997, the USGS (Shade, 1997) estimated recharge to be 29 mgd with a small amount of return irrigation. Although these later estimates indicate a higher recharge rate for Iao, none of these recharge estimates have been officially adopted by the CWRM through the WRPP process.

3.4.8. Ground-Water Pumpage

Within the Iao Aquifer System there are 48 listed wells, test holes, and tunnels (CWRM well database). Of the 48 sources there are 13 municipal wells operated by the MDWS, 10 observation wells, 10 irrigation wells operated by the County of Maui and Wailuku Sugar, and 6 unused sources. Staff field investigated to verify the status of non-DWS wells on July 16, 2002. The status summary of all wells in Iao is listed in Table 4.

Iao Aquifer System pumpage began in 1948 with the operation of Wailuku Shaft 33 (5330-05). Prior to the onset of pumpage, ground-water use was limited to tunnel water from 8 tunnels. Four of these tunnels (5330-01,02; 5332-03; and 5530-01) developed water from alluvium of Iao Stream, and in the case of 5530-01, in older alluvium at the mouth of Waiehu Stream (Stearns and Macdonald, 1942, pp. 197-198). The other 4 tunnels (5332-01,02; 5333-01,02) developed water from the dike complex and dikes within the caldera complex exposed in upper Iao Valley. According to Stearns and Macdonald (1942, p.197) these tunnels divert water that was already percolating into Iao Stream as springs. Therefore, tunnel flows are not considered pumpage from the aquifer and are accounted for in runoff quantities. Construction of these tunnels occurred decades before Wailuku Shaft 33 was constructed and developed, thus tunnel flows were at steady-state by the time the shaft was constructed.

Wailuku Shaft 33 (5330-05) was constructed in 1946 to provide additional irrigation water to sugarcane. The shaft is actually three large wells drilled below the pump room, rather than a skimming infiltration gallery that is more typical. The shaft began operations in 1948, and is the only operational source south of Iao Stream. In 1953 the average output was 9.7 mgd, though the installed capacity was 21.75 mgd. Pumpage from the shaft peaked in 1971 when the average pumpage was 11.7 mgd (Mink, 1986, p. 4). The Mokuhau Wells (Nos. 5330-09, 10, 11) constituted the first major well field developed in the Iao Aquifer, north of Iao Stream. Mokuhau Wells 1 and 2 were drilled in 1953 and Mokuhau 3 was completed in 1967. During the mid 1970's and early 1980's the Waiehu Heights wells, the Waihee wells, and Kepaniwai Well were added to supply potable drinking water. These sources are north of Iao Stream. The Commission tracks the 12-month moving average (MAV) of pumpage statewide. The 12-MAV is used since it incorporates a full climatic cycle at any given time.

Table 4. List of wells in the Iao Aquifer System.

Well	Well No.	owner/ user	type of well	date drilled	average production 12 MAV (mgd)	initial chloride (mg/L)	elevation at bottom of well (ft)	initial head (ft)	initial temp (deg F)
Waikapu 1	5130-01	State DOWALD	unused	1961		20	-206	12.0	69.8
Waikapu 2	5130-02	State DOWALD	unused	1974		13	-502	10.3	69.8
Waikapu Mauka	5131-01	Maui DWS	municipal	1999			-106	18.4	71.0
Waiale Prototype	5229-01	A&B (MAUI LANI)	lost	1978			-305		

Table 4. List of wells in the Iao Aquifer System (continued).

Well	Well No.	owner/ user	Type of well	date drilled	average production 12 MAV (mgd)	initial chloride (mg/L)	elevation at bottom of well (ft)	initial head (ft)	initial temp (deg F)
Ka Hale A Ke Ola	5230-01	Maui Econ Con	irrigation	1997			-51	4.1	73.0
Memorial Gym	5329-04	Maui Pks & Rec	irrigation				-30		
Baldwin High Sch	5329-05	Maui Pks & Rec	irrigation						
Baldwin High TH	5329-06	Maui County	unused	1939		152	-11	5.9	
Maui Stadium	5329-14	Maui DPW	irrigation	1970		285	-8		
Wailuku Arm	5329-17	U S Army	unused	1969			58		
Iao Tunnel	5330-01	Wailuku Sugar	irrigation	1900					
Iao Tunnel	5330-02	HC & S Co	irrigation	1900					
Field 63	5330-03	Wailuku Sugar	observation	1945			-20	30.6	
Wailuku Mill TH	5330-04	Wailuku Sugar	observation	1945		22	-525	16.4	
Wailuku Shaft 33	5330-05	Hawaii Land And Farming	Irrigation (municipal)	1946	5.025			26.0	
Mokuhau TH 1	5330-06	Maui DWS	unused	1950		280	-121	27.3	
Mokuhau TH 2	5330-07	Maui DWS		1951			-101	23.7	
Mokuhau TH 3	5330-08	Maui DWS		1952			-102		
Mokuhau 1	5330-09	Maui DWS	municipal	1953	1.396	16	-247	23.3	
Mokuhau 2	5330-10	Maui DWS	municipal	1953		16	-247	21.5	
Mokuhau 3	5330-11	Maui DWS	municipal	1967	2.599	30	-251		
Puuohala TH-C	5330-12	Wailuku Sugar		1975			-212	16.7	
Iao Valley TH	5331-01	Wailuku Sugar	observation	1940			-21	32.9	
Black Gorge Tunnel	5332-01	Wailuku Sugar	irrigation	1926					
Iao Tunnel	5332-02	Maui DWS	municipal	1939					
Field Gorge Tunnel	5332-03	Wailuku Sugar	sealed						

Table 4. List of wells in the Iao Aquifer System (continued).

Well	Well No.	owner/ user	Type of well	date drilled	average production 12 MAV (mgd)	initial chloride (mg/L)	elevation at bottom of well (ft)	initial head (ft)	initial temp (deg F)
Kepaniwai TH	5332-04	State DOWALD	observation	1973			459	675.0	
Kepaniwai	5332-05	Maui DWS	municipal	1974	0.795	25	413	677.0	69.8
Iao Needle Tunnel	5333-01	Wailuku Sugar	irrigation						
Iao Needle Tunnel	5333-02	Wailuku Sugar							
De Lara 1	5429-01	De Lara J	Lost	1947		528			
Papohaku Park	5429-02	Maui Pks & Rec	irrigation	1991		60	-55	24.7	
Waiehu Hts 1	5430-01	Maui DWS	municipal	1975	0.195	52	-338	18.0	
Waiehu Hts 2	5430-02	Maui DWS	municipal	1975	1.095	20	-206	18.0	
Waiehu TH-E	5430-03	Wailuku Sugar	observation	1976			-165	14.4	
Waiehu TH-D	5430-04	State DOWALD	observation	1975			-108		
Waiehu Monitor	5430-05	State CWRM	observation	1982			-1020		
Waiehu TH-B	5431-01	Wailuku Sugar	observation	1974		15	-66	16.6	
Waihee 1	5431-02	Maui DWS	municipal	1976	0.563		-182	13.6	72.5
Waihee 2	5431-03	Maui DWS	municipal	1976	1.641	189			71.6
Waihee 3	5431-04	Maui DWS	municipal	1981	2.772		-156	14.7	71.1
Waiehu TH	5529-01	U S G S		1935		32	-8	2.0	
Waiehu Golf	5529-02	Maui Pks & Rec	irrigation	1967			-66	3.6	73.9
Waiehu Tunnel	5530-01	Wailuku Sugar	observation						
Waiehu TH	5530-02	Wailuku Sugar	?	1933			-97	65.0	
Waiehu G C 1	5530-03	Maui Pks & Rec	unused	1995					
Waiehu G C 2	5530-04	Maui Pks & Rec	unused	1995			-73	8.4	73.9
Waihee TH A1	5631-01	Wailuku Sugar	observation	1974			-52	16.6	

Since 1991, the shaft has been operated by the MDWS at an average rate of 4.6± mgd. Figure 12 reflects the addition of new sources and shows a high of about 16 mgd in 1978. With changing irrigation methods in the early 1980's there was a reduction in pumpage from Wailuku Shaft 33, so that the average total aquifer was 10 mgd. Pumpage in the Iao Aquifer System steadily increased from 10± mgd the early 1980's to over 20 mgd in 1997. Since 1997, total 12-MAV aquifer pumpage has been reduced to about 16± mgd.

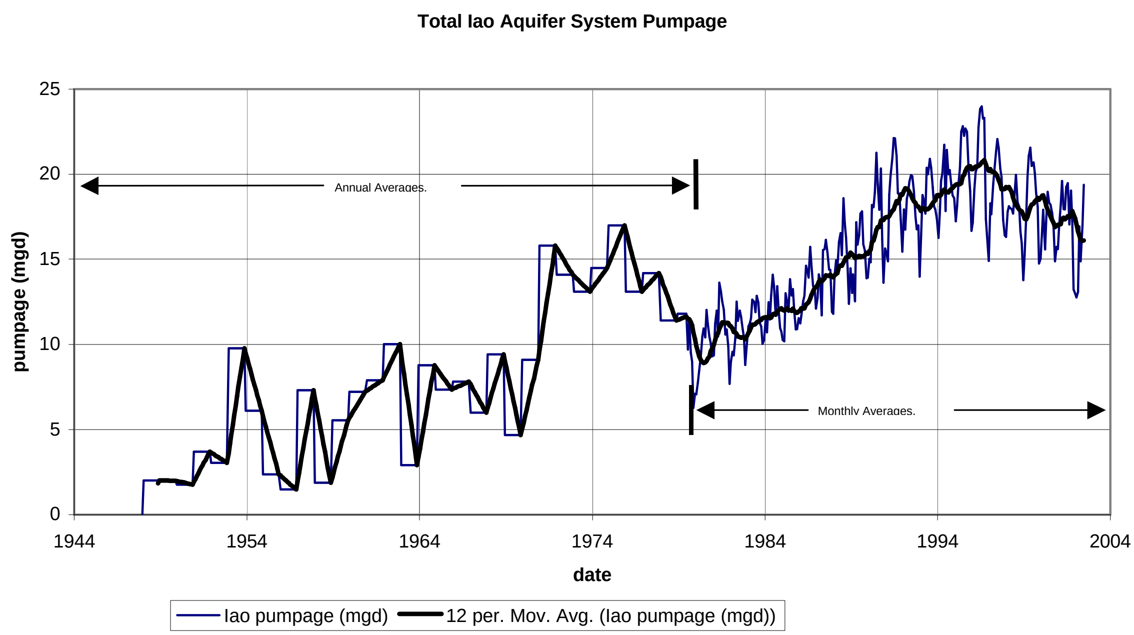

Figure 12. Total historical Iao Aquifer System pumpage

3.4.9. Water Levels

Water-level data in the Iao Aquifer System is sporadic during its first 35 years of data collection. Since 1983, data collection has been collected on a more regular basis.

Water levels within a basal aquifer in steady-state are described by the Ghyben-Herzberg principle. This principle recognizes the 1:40 ratio where fresh water (at an average specific gravity of 1.000) floats on salt water (at an average specific gravity of 1.025). For every foot of fresh water above mean sea level (MSL), the distance to the mid-point of the transition zone extends approximately 40 feet below MSL under steady-state. Under natural pre-development conditions, it is assumed that the aquifer is in a steady-state condition. Therefore, water levels under natural pre-development conditions are governed by the Ghyben-Hertzberg principle, geological boundaries, aquifer formation properties, recharge, and leakage. Coastal caprock formations are a geologic boundary that are less permeable than the basaltic formations and reduce leakage to the sea and, thus, generate relatively higher basal water levels and deeper fresh water lenses than areas with no caprock.

Water levels under developed, or pumping, conditions are governed by the Ghyben-Herzberg principle, geological boundaries, aquifer formation properties, recharge, leakage, and pumpage. However, in the short-term, pumpage is the primary governing factor that determines water-level elevations, not the transition zone mid-point elevation. Hydrologists know such a reaction as a "cone of depression" where water levels are drawn down in a fashion that extends outward from the pumping well (see Figure 18). When pumping ceases, localized pumping stresses only found in the pumping well (i.e. turbulence losses, well bore storage, etc.) dissipate and the water level will rise to match the Ghyben-Herzberg principle in relation to the location of the transition zone mid-point. Likewise, in the vicinity of a pumping well, water levels will rise to match the Ghyben-Herzberg principle in relation to the location of the transition zone mid-point. This rise will occur immediately after cessation of pumpage and continue over time at a slower rate**.** To illustrate this, Wailuku Shaft shut down for seven to eight months and water levels were continuously measured by the USGS (Figure 17 in Meyer and Presley, 2001). Data show that measured recovery at Wailuku Shaft 33 (5330-05) occurred over a four month period when the shaft was shut down. The water levels rose from 9± feet, MSL to 16.5± feet, MSL. Additionally, the MDWS, USGS, Mink, and CWRM conducted an aquifer-wide recovery test in January 2000 by turning off all pumping that showed water levels in the 3 Iao wells observed would recover within three months if pumping were shut-off completely. Therefore, these tests show that water levels in both pumping and observation wells will recover relatively rapidly and are not indicative of the overall condition of the aquifer.

Water levels in the southern portion of Iao illustrate that the overall condition of the aquifer is better than what it appears to be based solely on water levels north of Iao Stream. The new Waikapu Mauka well (5131-01) at the southern end of the Iao Aquifer System recorded a water level of 18.35 feet MSL in December 1999 and 16.9 feet MSL in June 2002. Another new deep monitor well has been funded by the State (to begin construction in 2003) and will be drilled in the southern portion of Iao will help confirm the depth of the transition zone and the health of the southern portion of the Iao Aquifer System.

The most important water-level data is the initial measurement made in 1948, where the first measured basal water level in the Iao Aquifer was 28± feet MSL (Mink, 1977) at Wailuku

Shaft 33. This pre-development water level represents the initial steady-state water level at this point in the Iao Aquifer. Under this initial condition the thickness of the lens at Wailuku Shaft 33 should have been -1120± feet taken to the mid-point of the transition zone (chloride concentration of 9,500 mg/L or 50 percent isochlor). This is the water level used in estimating sustainable yield using the robust analytical model (RAM; WRPP, 1990).

Figure 13 presents the majority of measured basal water-level data in the Iao Aquifer System for three observation test holes and Waiehu Deep Monitor Well. These observation well sites are on the north side of Iao Stream, and within the influence of the major pumping sources of the Mokuhau, Waiehu Heights, and Waihee Wells. Figure 13 clearly shows that the water levels behave similarly over time. In order to determine whether the water levels are influenced more by pumpage or by climatic conditions, Test Hole A-1 was chosen to plot with rainfall and pumpage (Figures 14 and 15).

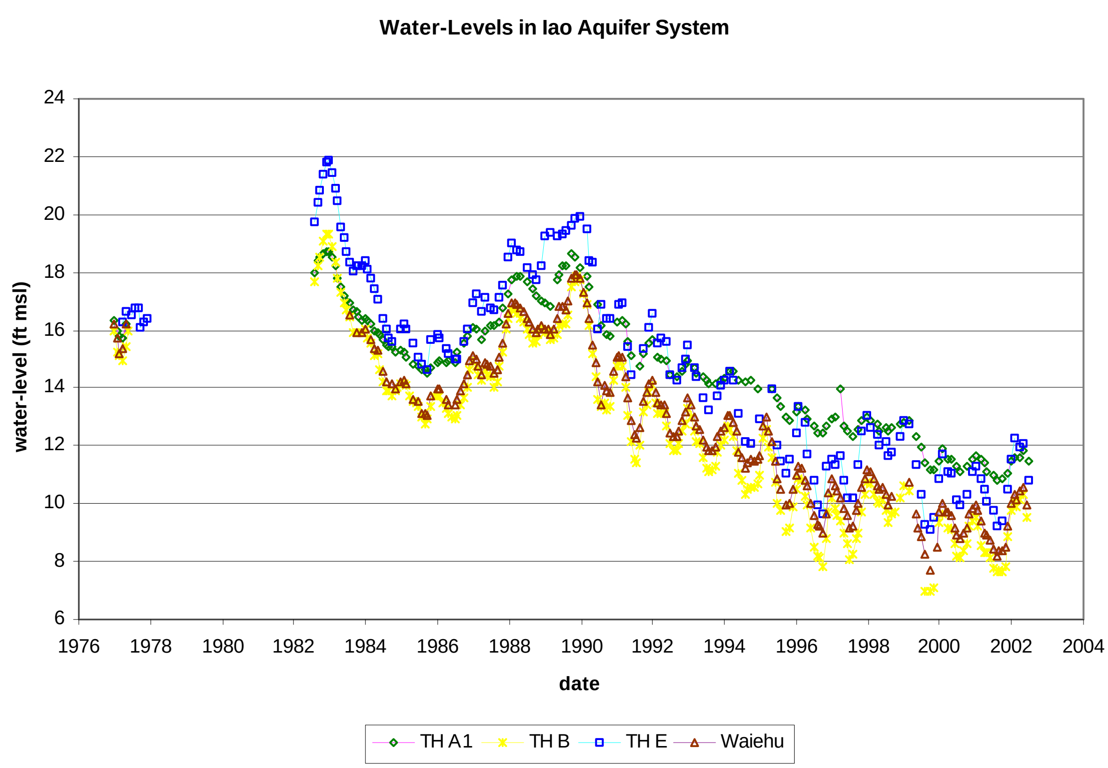

Figure 13. Water-Level comparison for the Iao Aquifer System

Figure 14 plainly illustrates that water levels closely track and are very sensitive to rainfall patterns. Therefore, it appears that rainfall correlates strongly with all observation well water levels in the Iao Aquifer Systems (Figure 13).

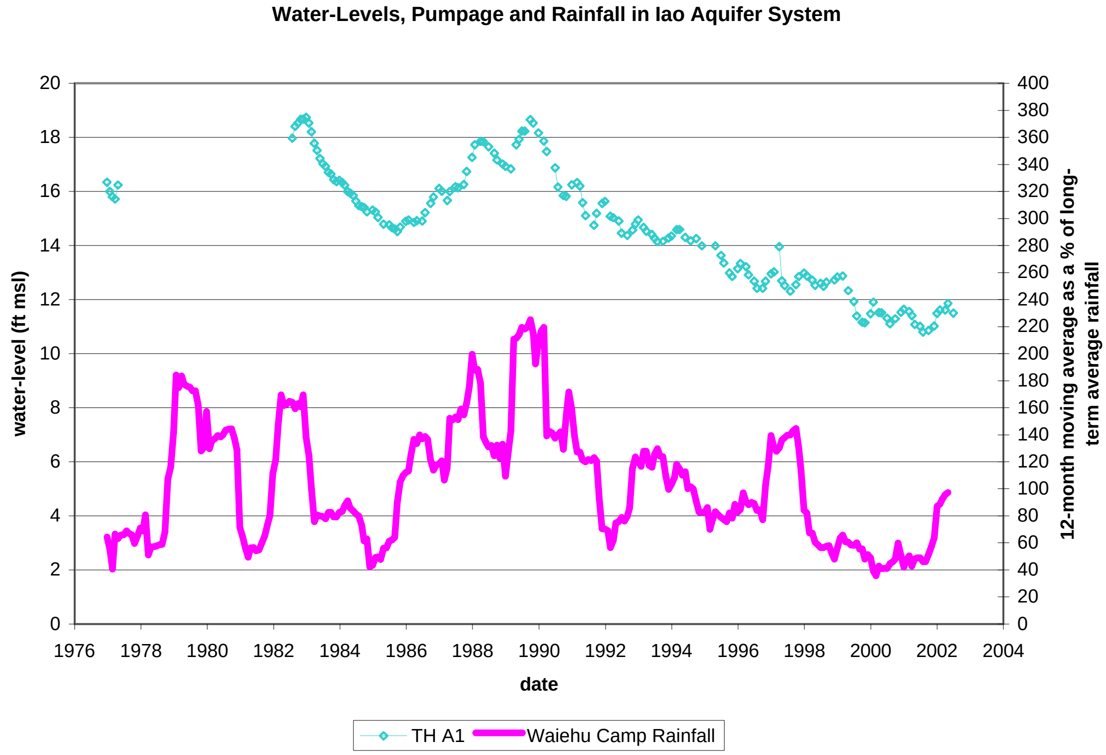

Figure 14. Rainfall and water-level comparison for Iao Aquifer System

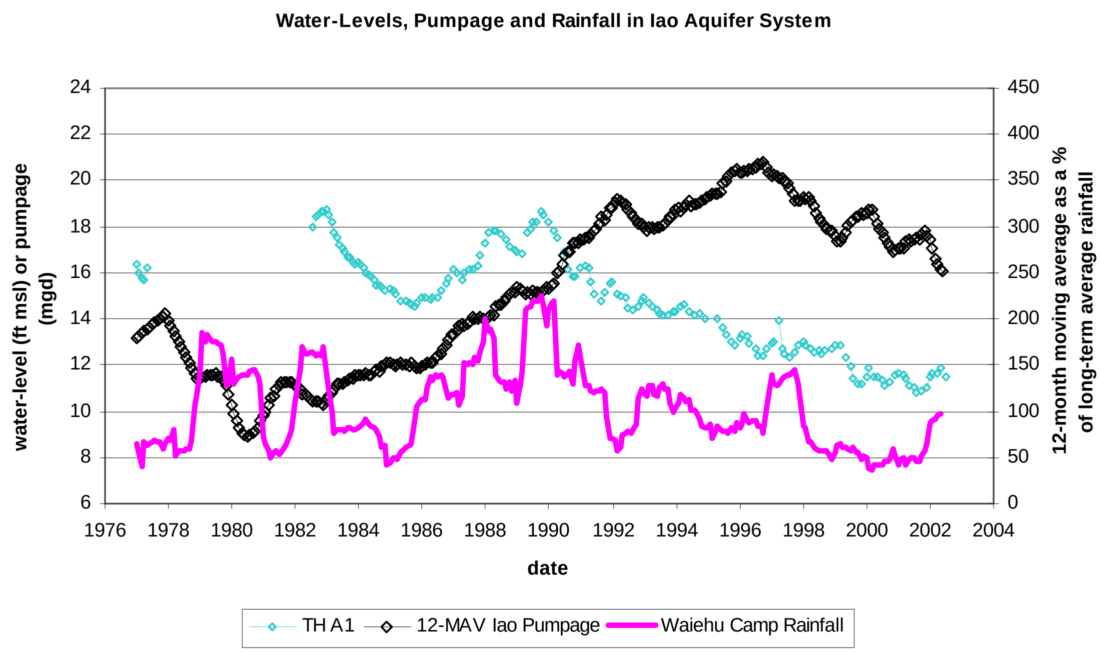

Figure 15. Rainfall and water-level comparison for Iao Aquifer System

When comparing rainfall, pumpage, and water-level response patterns, it appears that water levels follow rainfall patterns closer than pumpage, and Figure 15 illustrates these relationships. From 1986 to 1990, water levels rose in response to increased rainfall and increasing pumpage. This means that rainfall had the stronger influence than pumpage over water levels in this period. From 1997 to the present, water levels declined in response to severe drought and decreasing pumpage. This, again, shows rainfall having a stronger influence than pumpage over water levels. Indeed, correlation coefficients between rainfall and water levels (0.44) and pumpage and water levels (0.27) show that rainfall has a better correlation to water levels than pumpage in Iao. The USGS also recognizes that water levels are sensitive to rainfall (Meyer and Presley, 2001).

Figure 16 shows that water levels react more quickly to pumpage and rainfall than the transition zone mid-point. The inferred water level (equilibrium head) from the transition zone mid-point based on Ghyben-Herzberg at the Waiehu Deep Monitor Well is superimposed on Figure 16 to illustrate this point.

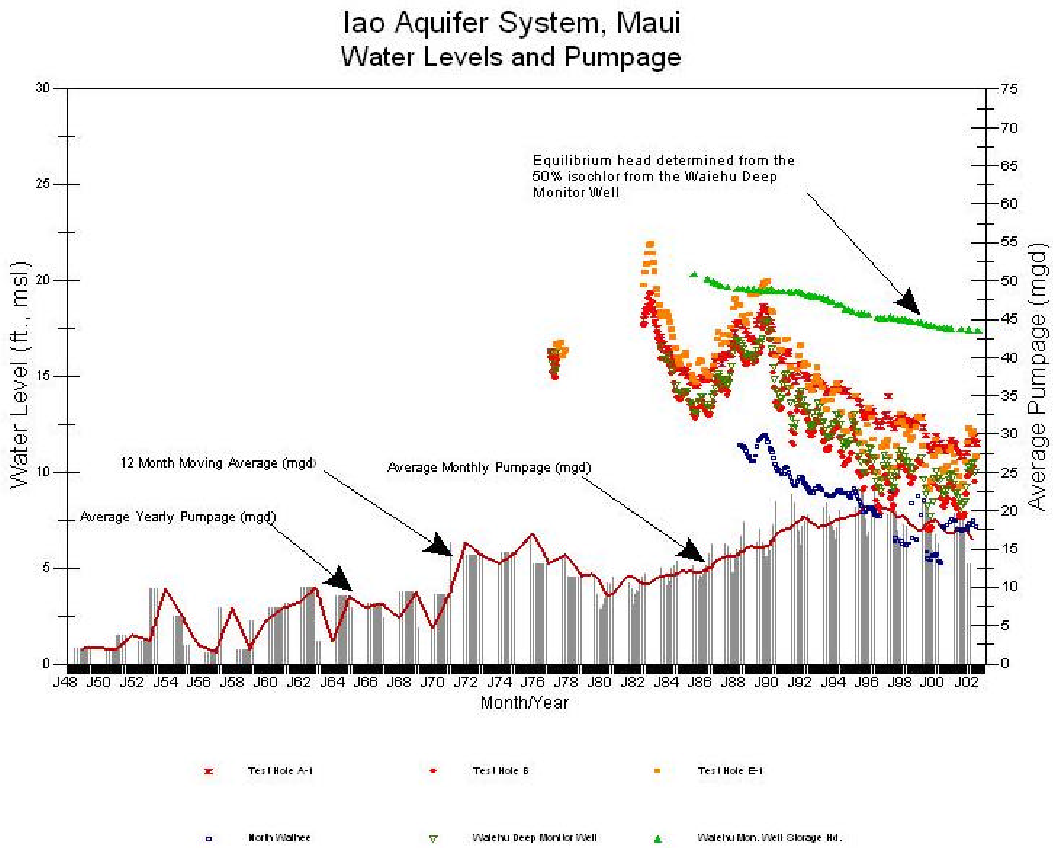

Figure 16. Water levels at the Waiehu Monitor Well and test holes
(Source: CWRM, State of Hawaii)

In addition to the lag of the transition zone mid-point relative to water levels, the transition zone appears to be thinning according to data collected from the Waiehu Deep Monitor Well (5430-05). Figure 17 illustrates this phenomenon.

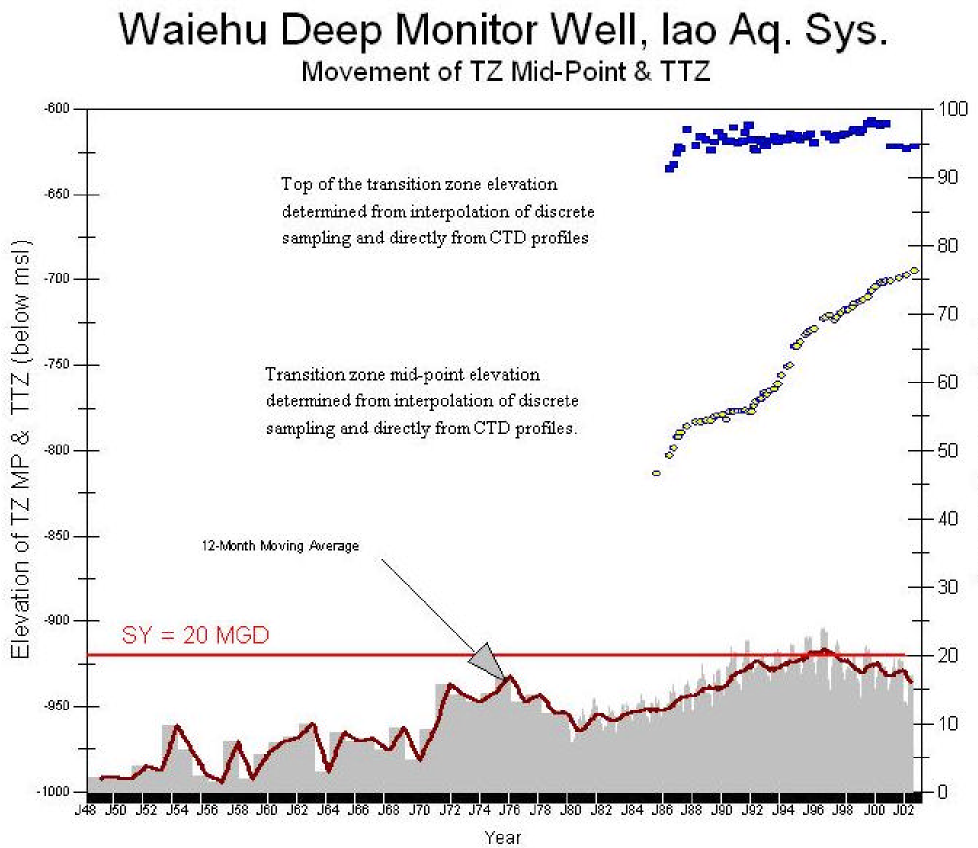

Figure 17. Waiehu Deep Monitor Well – transition zone data
(Source: CWRM, State of Hawaii)

The top of the transition zone is defined by the 250 mg/L chloride content (approximately 1000 µmhos/cm, or 2 percent seawater) and has been relatively stable from 1985 to the present, while the mid-point has risen 121± feet over the same period. The thickness from the mid-point to the top of the transition zone is thus presently 73 feet. By comparison, similar aquifers in Oahu have transition zone thicknesses between 250 and >500 feet at pumpages near their sustainable yields. The reason for this thinning phenomenon is uncertain, although both the USGS (Meyer and Presley, 2001, p.48) and CWRM are attempting to gather more data to address this issue. The rate of rise in the transition zone is currently 4.75 ft/year since 1998. At 4.75 ft/year, the mid-point of the transition zone would encroach on the well bottoms of Mokuhau and Waiehu Heights 1 wells within 94 and 75 years, respectively.

3.4.10. Water Quality

3.4.10(a) Chlorides

The chloride ion concentration is a measure of salinity used to indicate the potential potability of the resource. U.S. EPA guidelines suggest that the 250 mg/L chloride concentration is a taste standard and should be the upper limit for water supply systems. This secondary contaminant limit is based on aesthetics, rather than health reasons, and is not mandatory. Normally, the counties' water supply purveyors further endeavor to keep the delivered supply at 160 mg/L or less. Additional factors influencing chloride concentrations within individual wells in basal aquifers, such as Waihee, include geology, hydrologic properties of the aquifer, and well infrastructure (such as well depth, pump capacity, pumping schedules, etc.) and produce observable long-term trends.

Chlorides differ depending on hydrogeologic conditions. Dike-impounded sources, such as the Waihee Valley Tunnels, have high water levels and no known evidence of contact with seawater, which results in low chloride concentrations. However, no data has been collected to confirm that salt water underlies high-level aquifers, which would require drilling a well thousands of feet deep. Basal sources are more susceptible to changes in chloride concentrations because the Ghyben-Herzberg lens floats on denser salt water and, therefore is in direct contact with salt water. The contact between fresh and salt water is not sharp but rather diffuse in a zone of mixing, also known as the transition zone (See Figure 4 showing cross section). These transitions zones vary in thickness from aquifer to aquifer.

Chlorides are also impacted by well infrastructure. Localized chloride increases can be due to upconing effects resulting from high pumpage rates of individual wells, a well's depth, and aquifer properties in the vicinity of the pumping station. Within well batteries, such as Mokuhau, well spacing and location are also important when examining chloride trends in the individual wells of the battery. Localized chloride increases can be due to upconing effects resulting from high pumpage rates of individual wells, a well's depth, and aquifer properties in the vicinity of the pumping station (See Figure 18). Mokuhau well field has exhibited upconing, and as a result, Mokuhau Well No. 2 (located in the middle of the well field) has not been pumped, even intermittently, since 1997 due to excessively high chloride ion concentrations. In addition to localized upconing, well infrastructure can be affected by aquifer-wide shrinkage of the basal lens, which would increase chloride trends in all well sources. Deep wells, wells with large pump capacities, and wells closest to the ocean would be the first to experience higher chlorides.

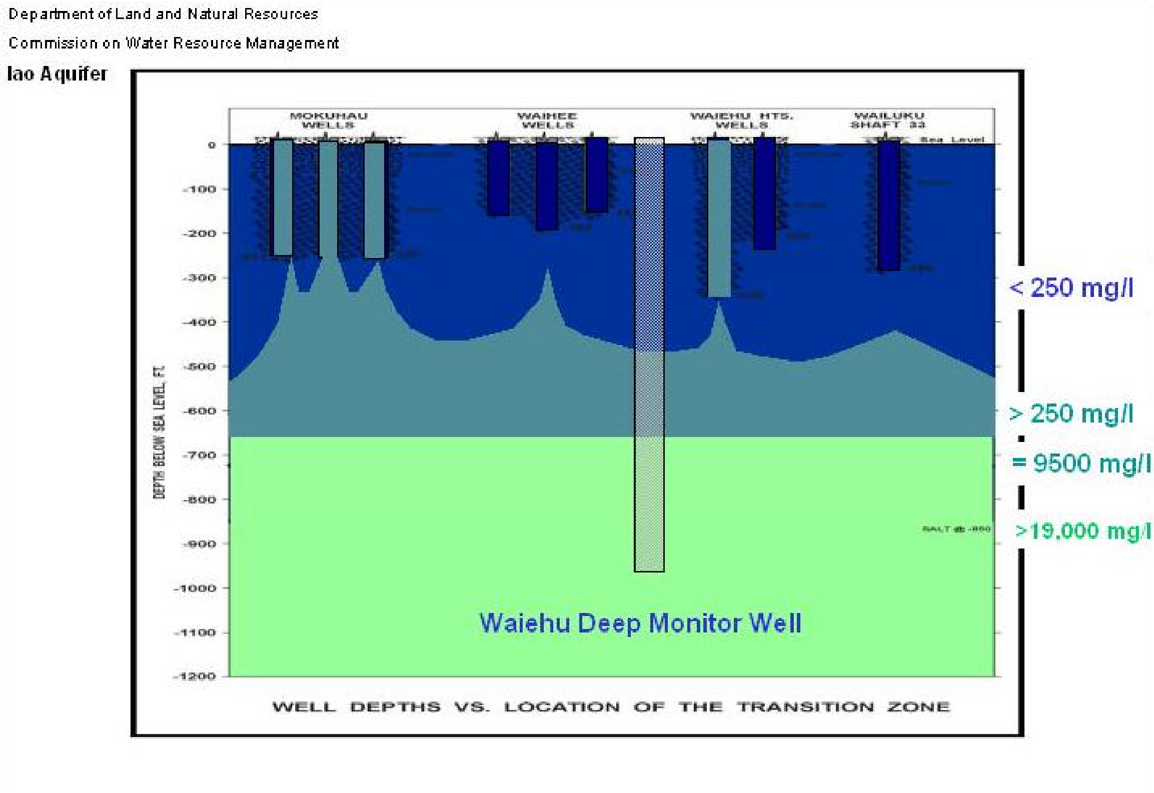

Figure 18. Localized upconing effects in Iao

Chlorides differ depending on hydrogeologic conditions. Dike-impounded sources, such as the Kepaniwai Well and Iao Tunnel, have high water levels and no known evidence of contact with seawater, which results in low chloride concentrations, only slightly greater than rainwater. Basal sources are more susceptible to changes in chloride concentrations because the Ghyben-Herzberg lens floats on denser salt water and, therefore is in direct contact with salt water. The contact between fresh and salt water is not sharp but rather diffuse in a zone of mixing, also known as the transition zone (See Figure 4 showing cross section). These transitions zones vary in thickness from aquifer to aquifer.

Deep monitor wells help us distinguish between localized upconing and aquifer-wide hydrogeologic conditions affecting salinity. Fortunately, salinity and temperature profiles conducted in the Waiehu Deep Monitor Well provide knowledge of regional changes, not only within the transition zone, but the fresh water core that is the potable portion of the basal lens.

Table 5 lists the initial chloride concentrations when current active wells in Iao Aquifer were first drilled and tested and provides a starting point to measure chloride trends in Iao.

Table 5. Initial chloride concentrations

WELL NAME	INITIAL CHLORIDE (MG/L)	YEAR (DRILLED)
Wailuku Shaft 33	**NA**	**1946**
Mokuhau 1	**16**	**1953**
Mokuhau 2	**16**	**1953**
Mokuhau 3	**30**	**1967**
Waiehu Hts. 1	**52**	**1975**
Waiehu Hts. 2	**20**	**1975**
Waihee 1	**15**	**1976**
Waihee 2	**NA**	**1976**
Waihee 3	**189**	**1981**
Waiehu Deep Monitor Well	**NA**	**1982**

Initial chloride values for Wailuku Shaft 33**,** Waihee 2, and the Waiehu Deep Monitor Well are unavailable but it is assumed that those concentrations were less than 30 mg/L. Waihee 3 initial chloride is believed to be an error since current chloride concentrations are much less.

Table 6 presents the average annual maximum chloride values for each of the Iao sources. Maui DWS samples each source weekly. The maximum chloride concentration represents the conservative view of a well's performance over time.

Year	Table 6. Average annual maximum chlorides in Iao basal wells								
	Waihee1	Waihee2	Waihee3	Mokuhau1	Mokuhau2	Mokuhau3	Waiehu1	Waiehu2	Sh33
1983	13	16	N/A	N/A	222	121	83	50	N/A
1984	15	16	N/A	N/A	171	104	92	49	N/A
1985	18	16	N/A	123	188	114	86	35	N/A
1986	17	16	N/A	114	161	148	82	52	N/A
1987	23	24	N/A	112	160	131	95	65	N/A
1988	38	30	N/A	76	205	150	92	90	N/A
1989	37	29	N/A	90	207	158	89	88	N/A
1990	39	21	35	114	377	184	76	65	N/A
1991	35	38	34	117	293	129	103	54	N/A
1992	29	46	30	125	141	101	93	47	45
1993	35	34	22	106	217	97	101	47	40
1994	41	42	35	102	279	128	113	55	48
1995	32	45	38	109	283	157	114	64	53
1996	23	36	19	85	334	140	123	47	40
1997	25	45	20	114	N/A	176	98	55	40
1998	29	57	20	139	N/A	93	78	53	42
1999	32	65	24	150	N/A	118	128	47	45
2000	46	53	N/A	198	N/A	135	174	58	46
2001	26	45	25	195	N/A	139	170	63	48

There are observable trends in the data presented in Table 6. Chloride concentrations in Waihee 2, the Mokuhau Wells, and Waiehu Heights 1 have trended upwards since 1983. Other wells show no trend since 1983. However, there is variability between wells within the same well field that can be the result of differences in well infrastructure (well depth, casing depth, the amount of open hole exposed), pumping schedules (that is, which wells are pumped longer or are rested more often, or are turned on and off more often), pump efficiency, and localized heterogeneity of aquifer properties.

The following sections present chloride data for the individual basal wells. These data are limited prior to 1975. Figures 19 through 28 present available monthly maximum chloride data for individual wells from USGS and MDWS, total average Iao monthly pumpage, total average station pumpage, total average well pumpage plotted over time.

Mokuhau Wells

The Mokuhau Wells (Nos. 5330-09, 10, 11) constituted the first major well field developed in the Iao Aquifer. Mokuhau Wells 1 and 2 were drilled in 1953 and Mokuhau 3 was completed in 1967. Initial chloride values are presented in Table 5. These chloride values are low due to the low aquifer pumpage at the time (<10 mgd total). The Mokuhau Wells bottom hole elevations range from –247 feet, MSL to –251 feet, MSL. Installed capacity at the Mokuhau Wells has two wells at 2,800 gpm (4 mgd each; Mokuhau 1 and 2) and one well at 4250 gpm (6 mgd; Mokuhau 3).

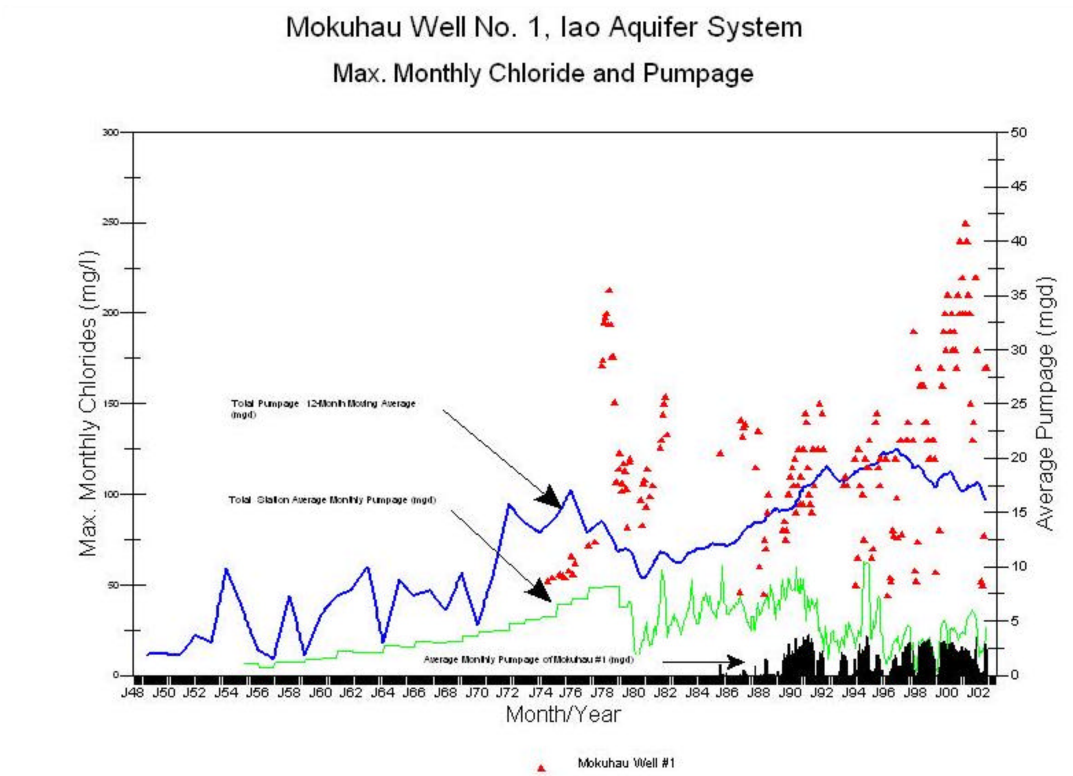

Figure 19. Maximum monthly chloride and pumpage at Mokuhau 1.

Figure 19 shows increasing maximum chloride concentrations in the late 1970's to early 1980's when the Waiehu Heights and Waihee Wells were put online, even though total pumpage from the

Mokuhau station had decreased from 8.3 mgd in 1977 (Mink, 1986) to <5 mgd. During the mid-1980's through the mid-1990's the average monthly maximum chloride value remained < 150± mg/L. In the late 1990's to present, the chloride concentration from this well increased, partly as a response to the drought conditions and partly to increased sustained pumping because of Mokuhau 2 being taken offline.

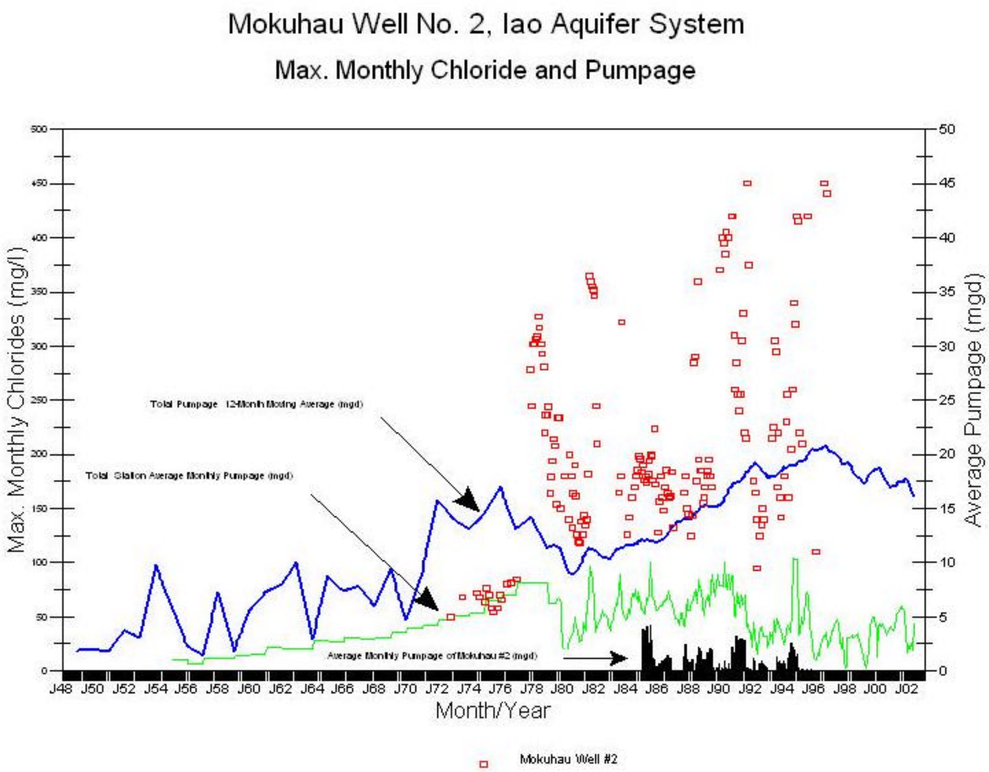

Figure 20. Maximum monthly chloride and pumpage at Mokuhau 2

Figure 20 indicates that Mokuhau 2 chloride concentration maintained 50-75 mg/L for the first years of operation, and increased significantly when the Waiehu Heights and Waihee stations began to operate. The location of Mokuhau 2 in the middle of the well field has increased the severity of the saltwater intrusion (Mink, 1986). The Mokuhau well field is set in a relatively confined area, with Mokuhau 2 located 50 feet from Mokuhau 1 and 45 feet from Mokuhau 3 (Mink, 1986, p.9). Mokuhau 2 has been effectively non-operational since 1995, even though samples were collected through 1997. Wailuku Shaft 33 has been brought online to alleviate some of the stress in the Mokuhau Well field, but reduced pumpage at Mokuhau has not overcome upconing problems.

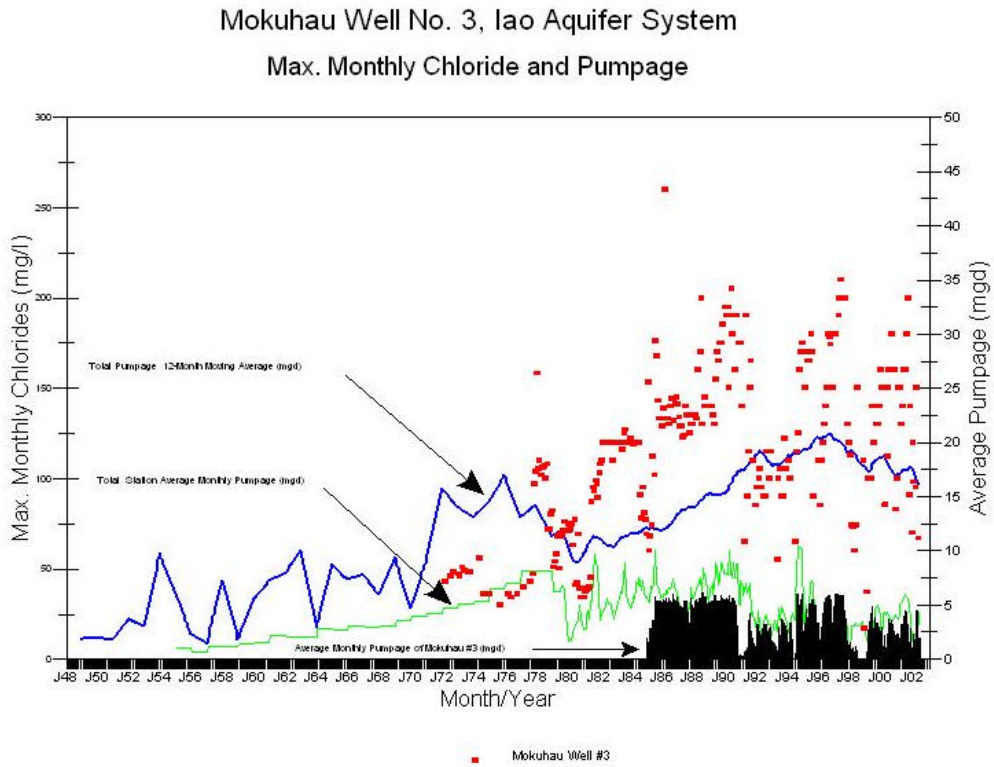

Figure 21. Maximum monthly chloride and pumpage at Mokuhau 3

Mokuhau 3 has an installed capacity of 6 mgd, and as can be seen in Figure 21, pumps the majority of the water from the Mokuhau well field. The chlorides have increased over time; however, in recent years, the average maximum monthly values range <100 to 200± mg/L. The higher values could be related to when the sample is collected vis-à-vis the pumping schedule.

<u>Waiehu Heights Wells</u>

The Waiehu Heights Wells (well nos. 5430-01,02) were drilled in 1975. Pump test results indicated that these wells were successful and were outfitted with 1.79 mgd pumps (1250 gpm) each. Waiehu Heights Well 1 (5430-01) is drilled deep having a bottom hole elevation of –338 feet, MSL. Waiehu Heights Well 2 (5430-02) has a bottom hole elevation of –206 feet, MSL. Table 5 shows that the initial chloride value for Well 1 was 52 mg/L and for Well 2 was 20 mg/L, which is a reflection on the disparity of their bottom hole elevations.

Figures 22 and 23 present available monthly maximum chloride data for the Waiehu Heights Wells from USGS and MDWS, total average Iao monthly pumpage, total average station pumpage, total average well pumpage plotted over time.

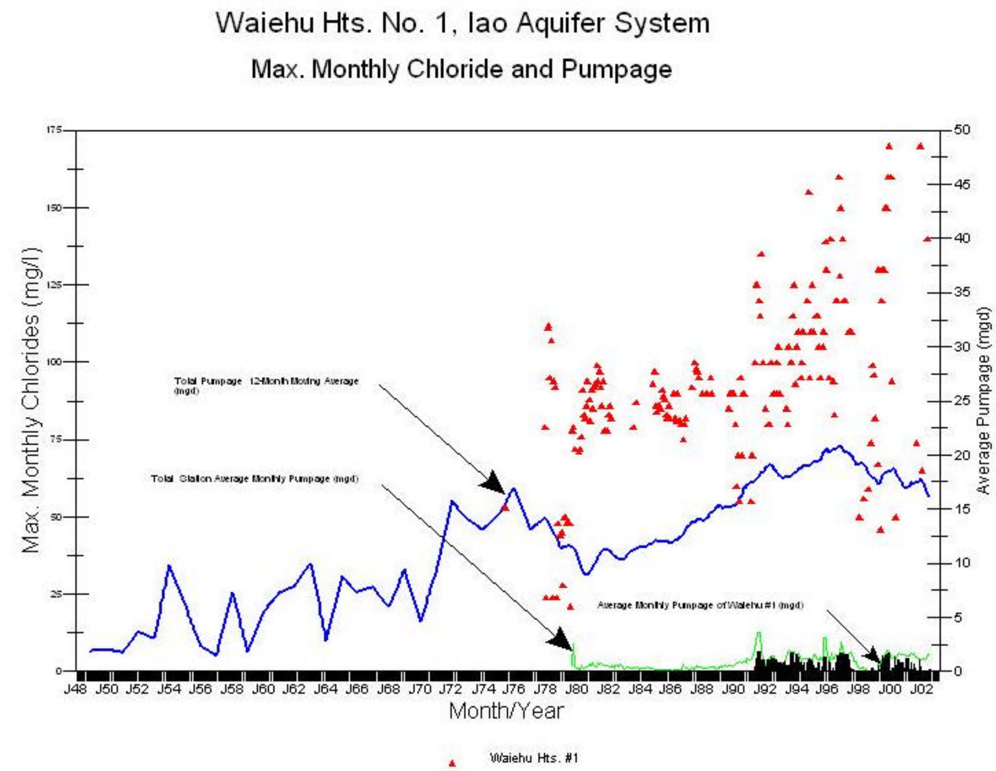

Figure 22. Maximum monthly chloride and pumpage at Waiehu Heights 1.

Figure 22 shows the total Waiehu Heights well field draft to be less than 2.5 mgd. Well 1 producing the majority of the station's output until the last several years. Because this well is so much deeper than Well 2, the average maximum monthly chloride values have been increasing since 1980, and increased significantly since the early 1990's when total aquifer pumpage increased to 15 mgd. This station is in the vicinity of the Mokuhau and Waihee well fields. However, as in the case of Mokuhau 3, the average maximum values fluctuate between 50± mg/L and 175± mg/L. The degree of fluctuation could be related to sampling schedules as described previously.

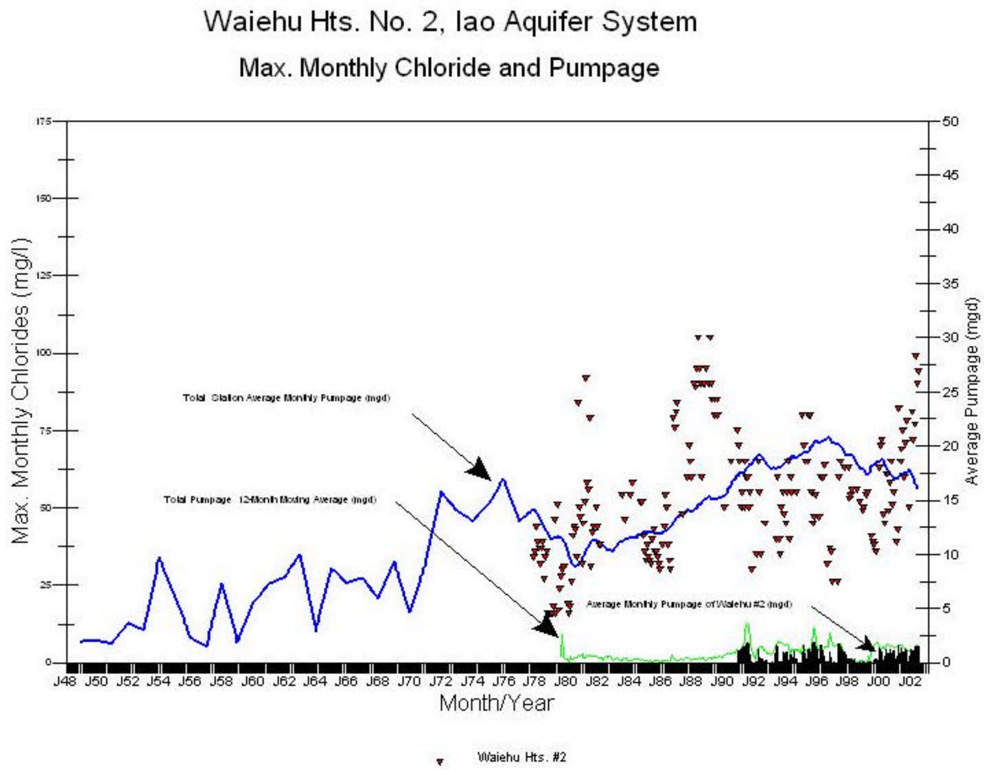

Figure 23. Maximum monthly chloride and pumpage at Waiehu Heights 2.

From Figure 23, Waiehu Well 2, though having an identical installed capacity as Well 1, produces better quality water because its bottom elevation is much shallower. Even though there are fluctuations in monthly maximum values, the chlorides range from slightly >100± mg/L to 25± mg/L. Again, monthly fluctuations are the result of sampling versus the runtime of the pump.

Waihee Wells

The Waihee Well field (5431-01,02,04) was drilled at about the same time as the Waiehu Heights wells. Two of the wells have an installed (5431-01,02) capacity of 2800 gpm each (4 mgd) and well no. 5431-04 has an installed capacity of 3480 gpm (5 mgd). These wells are shallower than those at Mokuhau and Waiehu Heights. The deepest is Waihee 1 at –182 feet, MSL. The shallowest is Waihee 3 at –156 feet, MSL.

Table 5 shows that the initial chloride values range considerably. Waihee 1 was 20 mg/L, while Waihee 3 was 189 mg/L (again, this value is thought to be an error). There is no initial chloride value for Waihee 2.

Figures 24 through 26 present the data for the individual wells within the well field. Total station output is about 7 mgd. However, since about 2001, the station produces about 5 mgd.

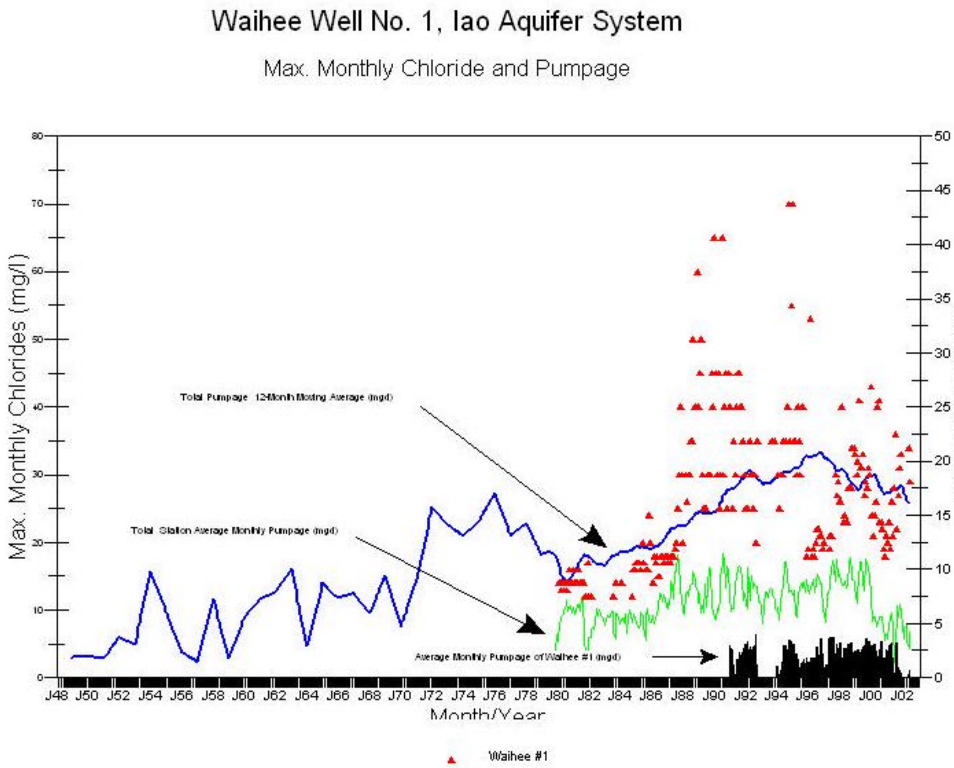

Figure 24. Maximum monthly chloride and pumpage at Waihee 1.

Waihee 1 produces about a third of the total withdrawal, or about 2.5 mgd average pumpage. In the late 1980's through the mid 1990's the average maximum monthly chlorides ranged from <20 mg/L to a high of 70 mg/L. Since 1997, the fluctuations of chloride concentrations are tighter, and are generally between 20 to 40 mg/L.

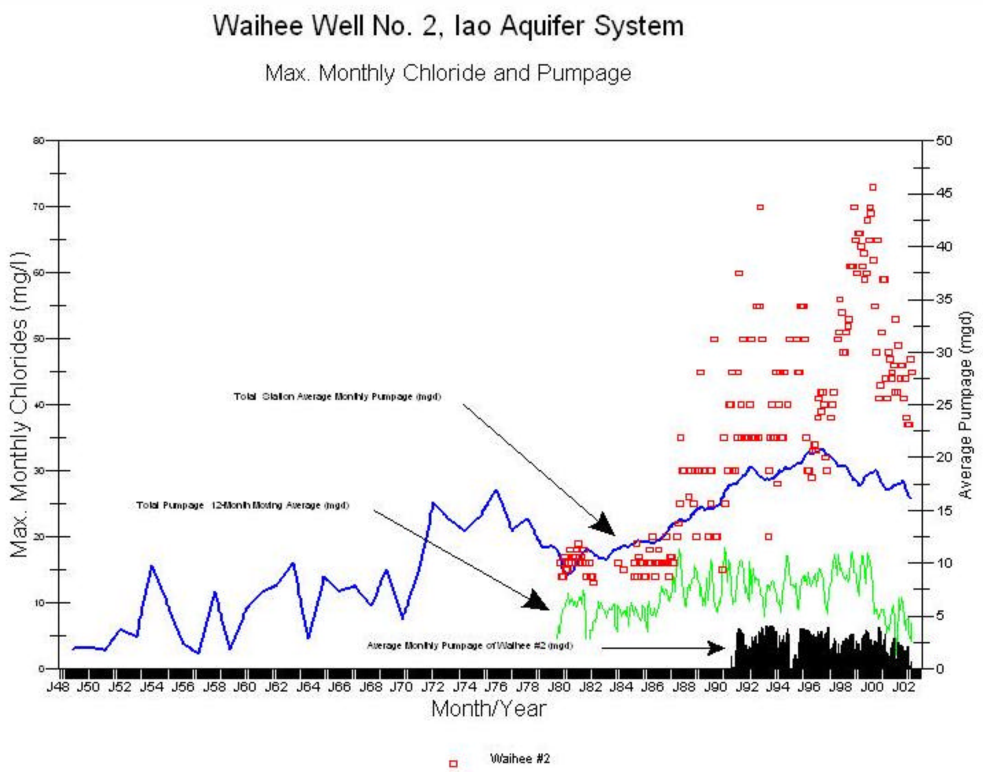

Figure 25. Maximum monthly chloride and pumpage at Waihee 2.

Waihee 2 also produces about one third of the station's water. Despite the early low concentrations during the 1980's chlorides have risen as total aquifer pumpage increased throughout the 1990's until the production at the station decreased to 5 mgd in the year 2001. Maximum monthly chloride values dropped to 40± mg/L as a result of low pumpage.

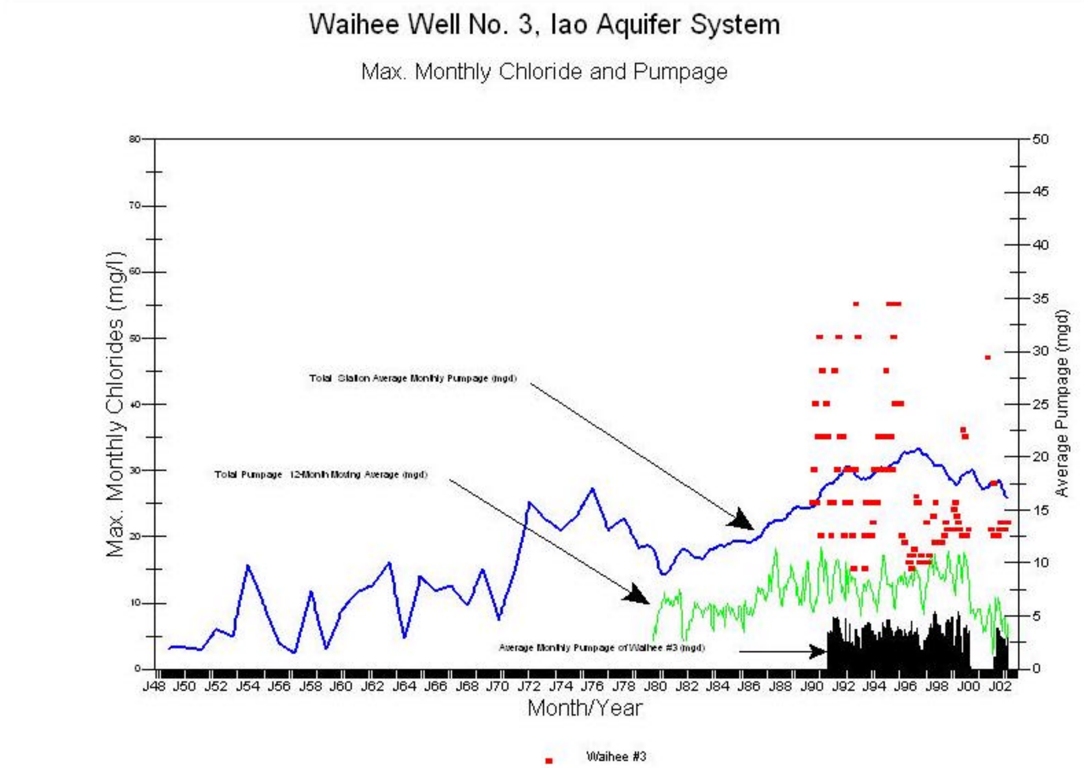

Figure 26. Maximum monthly chloride and pumpage at Waihee 3.

Waihee 3 has the largest installed capacity at the well field and also exhibited the greatest fluctuation of chloride concentrations over the period of high total aquifer pumpage. Although the maximum chloride values did not exceed 60 mg/L, there was a dramatic decrease in the late 1990's as MDWS cut back total Iao pumpage. Even though the station cut back in 2001, the chlorides have remained steady at about 20± mg/L since 1997. There are a few months where the sample maximum value jumped between 35-50± mg/L, but these data anomalies do not seem to reflect what is the station norm.

Wailuku Shaft 33

Wailuku Shaft 33 (5330-05) was constructed in 1946 to provide additional irrigation water to sugarcane. The shaft is actually three large wells drilled below the pump room, rather than a skimming infiltration gallery that is more typical. The shaft began operations in 1948, and is the only operational source south of Iao Stream. In 1953 the average output was 9.7 mgd, though the installed capacity was 21.75 mgd. Pumpage peaked in 1971 where the average pumpage was 11.7 mgd (Mink, 1986, p. 4). Since MDWS began to operate the shaft in 1991, the average pumpage is 4.6± mgd. Figure 27 presents the chloride and pumpage history of this source.

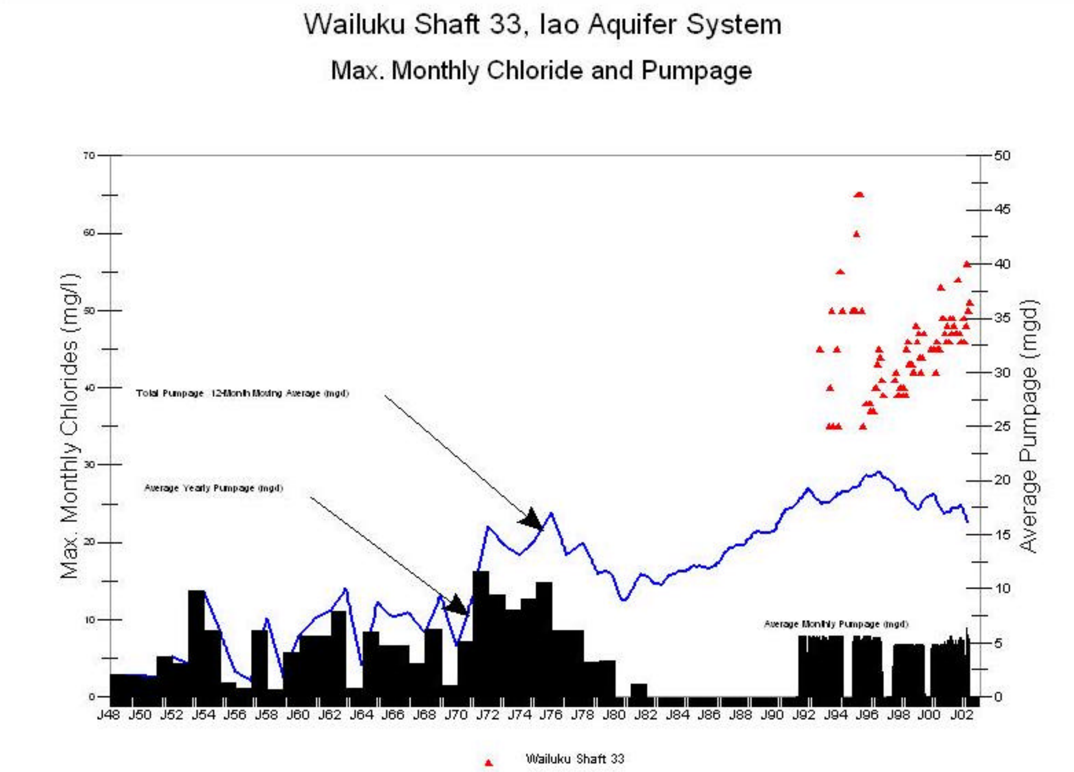

Figure 27. Maximum monthly chloride and pumpage at Wailuku Shaft 33.

Since Wailuku Shaft 33 was put back into operation in 1991, the maximum monthly chloride concentration has increased from 35± mg/L to 55± mg/L. Despite pumping almost 5 mgd, the water quality remains excellent.

Kepaniwai Well

The Kepaniwai well (5332-05) is located within the high-level dike-impounded portion of the Iao Aquifer System. The well was drilled in 1974 at an elevation of 713 feet, MSL and encountered water at an elevation of 676± feet, MSL. The well is 300 feet deep, and because of the high drawdown encountered during the testing phase of construction, the 1 mgd (700 gpm) pump is set at 179 feet below the surface. Average pumpage is 0.67 mgd. Figure 28 presents the chloride and pumping history of this source.

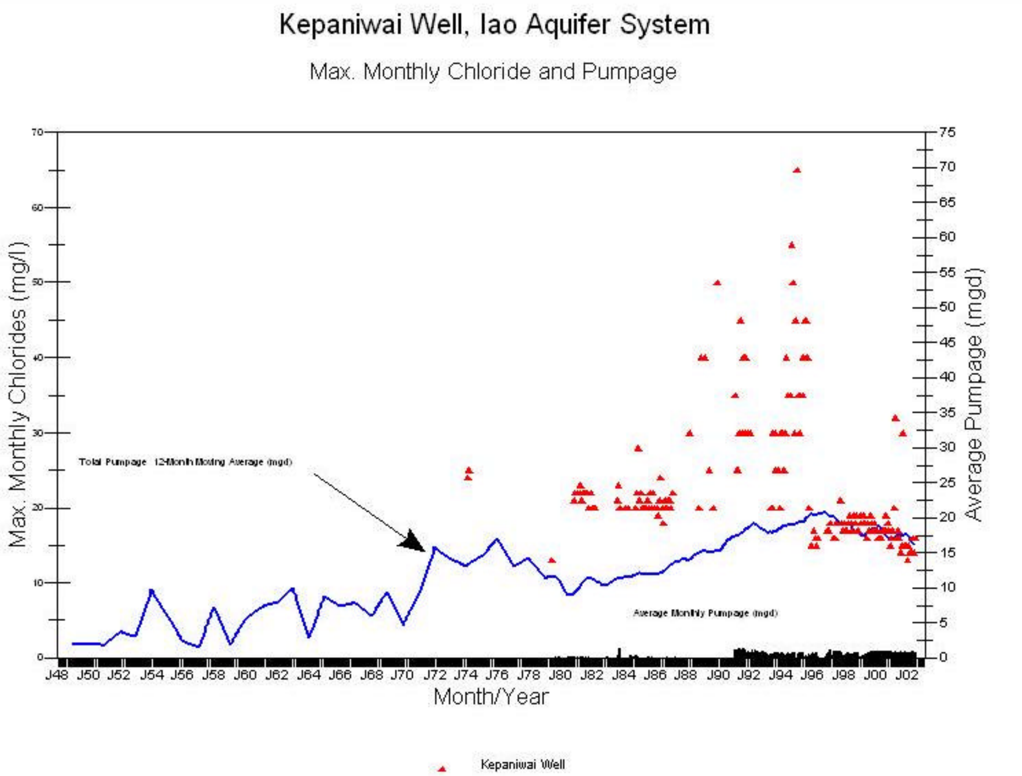

Figure 28. Maximum monthly chloride and pumpage at Kepaniwai Well.

The chloride data generally show typical dike-impounded values between 10 and 20 mg/L. However, anomalously high values are shown in the data set. One anomalous measurement of 135 mg/L was reported in September 1991. The anomalous values may be either caused by sampling/analytical error or by some other mechanism (e.g. geothermal convection). More research will be needed to determine if the high chloride values are natural or the result of error.

3.4.10(b) Temperature

Visher and Mink (1964, p. 122) report that the temperature of water recharging the Koolau aquifer averages 67.5° F, while ground-water temperatures in Honolulu average about 70° F (21.1° C). Mink (1977, pp. 17-18) notes that ground-water temperatures ranging from 71° F (21.6° C) to 72.5° F (22.5° C) pumped from Shaft 33, the Mokuhau Wells, and the Waihee Wells are warmer than expected. Given the elevation and cooler temperature of the recharge area, estimated at 67° F (19.5±°C), ground-water temperatures should be cooler. The Kepaniwai Well, drilled into a dike compartment, produces water at 69.8° F (21.0° C). He concludes that the anomalous basal water temperatures could be from the following:

1) Recharge originating at low elevations.

2) Return irrigation water providing for a large portion of recharge. With the reduction of agriculture irrigation since the mid 1990's over the Iao Aquifer, return irrigation water is no longer a major component of recharge.

3) Ground-water temperatures are in balance with the geothermal gradient; therefore, the ground-water flow is sluggish and total recharge limited.

Continual temperature profiling of the Waiehu Deep Monitor well by CWRM as a component of conductance profiling, is shown as Figure 29. This profile is essentially identical to the first conductivity log completed in 1999. The profile shows that temperature at the surface is 21.9° C (71.4° F) and steadily decreases to 20.8° C (69.4° F) at elevation –425± feet, MSL, where a cold water zone that is 19.5° C (67.1° F) extends to –570± feet, MSL. The cold water zone represents recharge from the higher mountainous interior of West Maui. Below the cold water zone, temperatures increase with increasing salinity. The transition zone mid-point temperature is 20.3±° C (68.5° F), while the bottom temperature is 22.9±° C (73.2° F) at –925 feet, MSL.

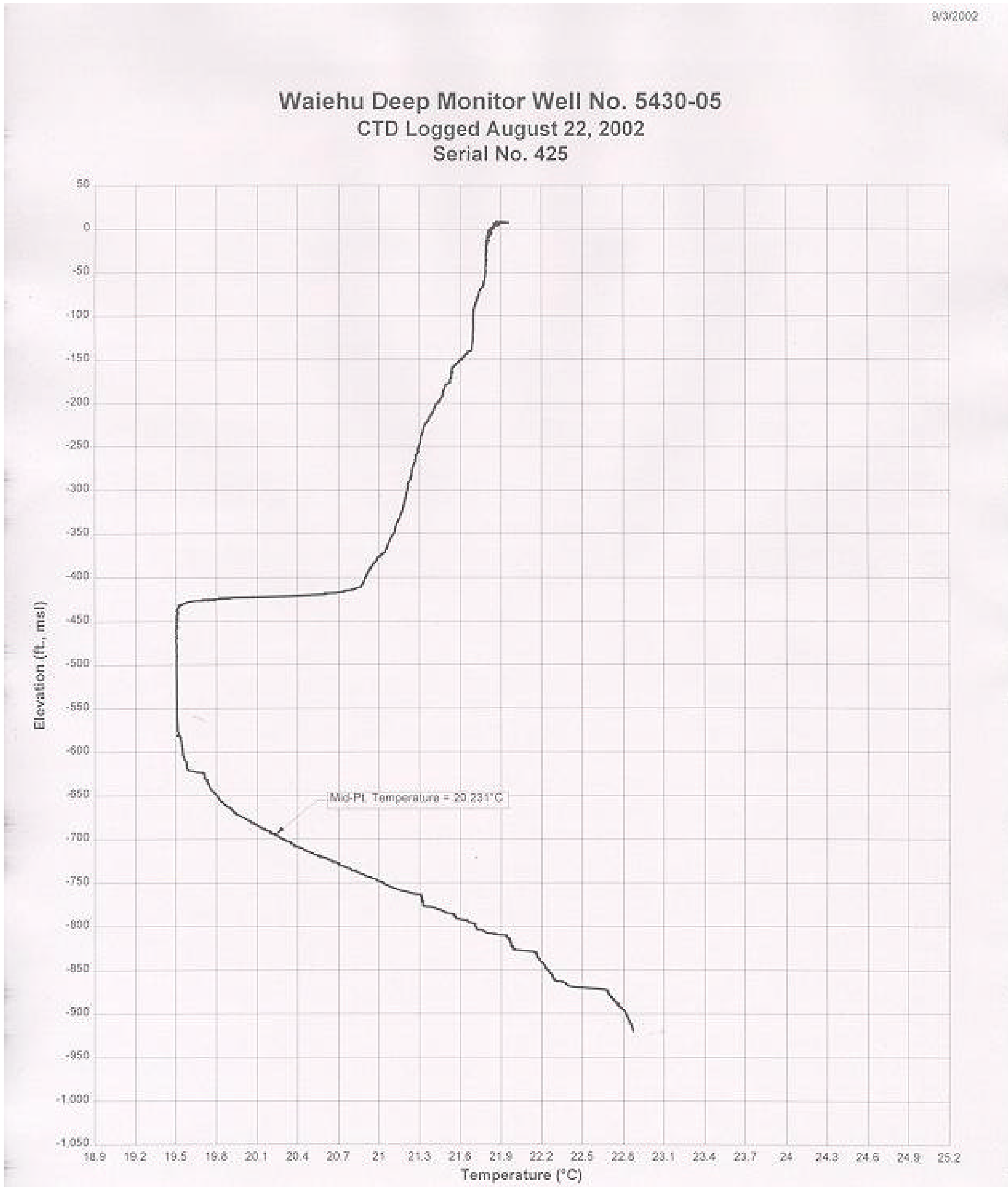

Figure 29. Temperature profile through Waiehu Deep Monitor Well.

3.4.10(c) Contaminants

The Department of Health (DOH) Safe Drinking Water Branch (SDWB) has tested all Iao drinking water wells for organic compounds and inorganic contaminants. SDWB did not detect any organic contaminants. However, SDWB did detect inorganic contaminants; chromium and fluoride in concentrations well below EPA maximum contaminant levels (MCL).

3.4.11. Sustainable Yield

Under the State Water Code, sustainable yield is defined as follows:

HRS §174C-3 - *"Sustainable yield means the maximum rate at which water may be withdrawn from a water source without impairing the utility or quality of the water source as determined by the commission."*

In determining sustainable yields, the Commission distinguishes between optimal potential development of an aquifer and the man-made limitation on withdrawals imposed by existing infrastructure. Under the WRPP, sustainable yields are derived by the RAM and address the optimal potential development perspective for planning and managing purposes. RAM was never intended to address constraints imposed by actual infrastructure perspective. Indeed, USGS Report WRI 00-4244 (Oki and Meyer, 2001) shows that predicted spatial distribution of water levels in an optimal development model such as RAM will differ from the predicted water-level distribution of a model that accounts for sub-optimal infrastructure. To address the infrastructure perspective, a regional numerical model is required. Also, it should be understood that there is no single optimal configuration of infrastructure given the need to balance economic vs. hydrologic constraints.

The Commission has revised sustainable yields when ‘acceptable’ numerical models have been developed **and** there has been competition amongst large users (e.g. Ewa-Kunia, Waipahu-Waiawa, and Kualapuu Aquifer Systems). There has been another numerical model developed to address infrastructure constraints to sustainable yield (e.g. Lanai, Ewa Caprock) but the Commission did not revise the WRPP sustainable yields. In the case of Lanai, sustainable yield was not revised due to the lack of competition between large users. In the case of the Ewa Caprock, the Commission determined to use chloride limits to non-potable individual wells to manage and protect the aquifer. Therefore, given the facts that the MDWS is the sole large user in Iao and no numerical model exists for Iao, it would seem more appropriate to use the optimal potential development perspective at this time. However, the county is pursuing the development of a 4.5-year, $1 million dollar numerical modeling project, that includes Iao, to be done by the USGS (June 28,2002 letter from USGS to MDWS). Once this project is done, the Commission may then consider revising Iao aquifer sustainable yield from the infrastructure perspective.

The current official CWRM estimate for sustainable yield is 20 mgd, as adopted through the WRPP. However, the original official recharge estimate of 15 mgd is less than the sustainable yield of 20 mgd. Since 1995, revised estimates for recharge have been presented for Iao (see Table 2) but not officially adopted through the WRPP procedures. These studies suggest that recharge in the WRPP is too low and suggest that the current sustainable yield is appropriate.

Ultimately, actual field data should reconcile and verify that pumping at a sustainable yield estimate is not endangering the aquifer. Currently, data suggest that pumping at 20 mgd will not endanger the aquifer but may reduce the utility of some of the deeper MDWS sources (Mokuhau, Waiehu 1). The current 12-MAV is 16±mgd (80 percent of sustainable yield) is much less than that seen during the last Commission designation decision and may improve conditions at some pumping wells.

3.5. Waihee Aquifer System Hydrology

3.5.1. Ground-Water Occurrence

Ground water in the Waihee Aquifer System occurs in two areas of the Wailuku Volcanics: 1) upper regional high-level dike confined water, 2) lower regional basal water (Figure 4). There are also small-perched aquifers in high rainfall areas of the Honolua Formation (Stearns and Macdonald, 1942 p 175). Potable ground water in the Waihee Aquifer System is found in both the high-level and basal portions of the system. Only the basal aquifer is currently used for potable water. The basal water zone extends about a mile inland from the coast (Meyer and Presley, 2001; Yamanaga and Huxel, 1970 p. 25).

The Waihee River forms the southern boundary of the basal aquifer. The low-permeability valley fill of the streambed forms a partial barrier to ground-water flow (Mink, 1997). See Figure 2 map of Iao and Waihee boundaries. Therefore, the valley fill delineates the aquifer system from the Iao Aquifer System. The northern boundary of the Waihee Aquifer System is defined by Kahakuloa Stream. The delineation of aquifers further inland is probably less pronounced. It appears from the streamflow data that the deeply entrenched Waihee River probably intercepts dike-impounded aquifer flow from other aquifer systems.

3.5.2. Rainfall

The Waihee Aquifer System receives a substantial amount of rainfall but with great geographical variation. Mean annual rainfall within the system varies from about 40 inches over the relatively dry coastal region to almost 350 inches at the head of the aquifer system (Giambelluca and others, 1986, report R76). Table 7 lists rain gauge stations and the average rainfall for Waihee Aquifer System. Rainfall data over the aquifer system is very sparse. For this reason we have included data from Eke and Puu Kukui raingages as examples of interior raingages for the Waihee Aquifer System. However, an isohyetal map can be constructed using existing West Maui rainfall data. Figure 8 shows the distribution of mean yearly rainfall over the region and the location of raingages. Previous estimates of total rainfall in million gallons per day are tabulated in the water balance table (Table 8).

Table 7. Summary of rainfall station data in or near the Waihee Aquifer System

Station	Station No.	Gage Elevation (ft)	Mean Annual Rainfall (in)	Median Annual Rainfall (in)	Period of Record or Reference	Note

Waihee Valley	482	300	43.2	41.3	1936-2002	
Eke	481.3	4602	255.7	251.3	1913-1933	not in Waihee
Puu Kukui	380	5788	391.6	381.0	R76, p 202	not in Waihee
Puu Kukui	380	5788	380.9	n/a	1928-2002	not in Waihee
Kahakuloa Mauka	482.3	650	37.72	34.5	1967-1983	

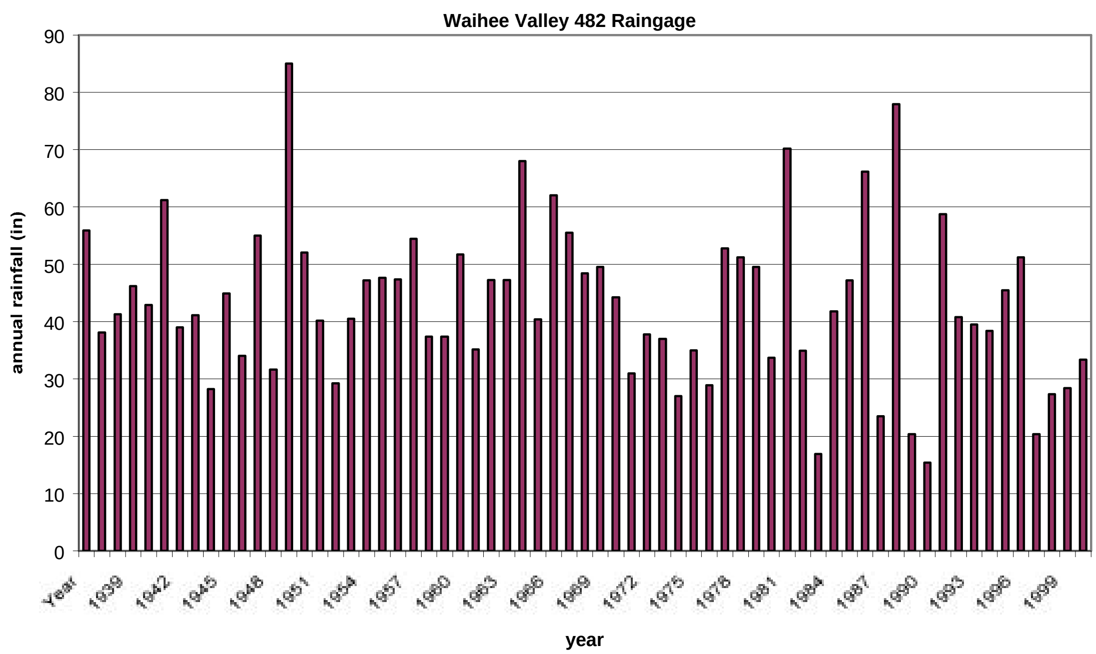

Figure 30. Annual rainfall at station no. 482 in Waihee Aquifer System

Station No. 482 in Waihee Valley recorded the most continuous daily record of rainfall within the aquifer system. Figure 30 shows annual rainfall data at Station No. 482 over the entire period of record.

Figure 31 illustrates another way of looking at rainfall data from Station No. 482. Annual rainfall is taken as a percentage of long-term historical average mean for this gage. Therefore, rainfall percentages greater than 100 percent represent a wet year and rainfall percentages less than 100 percent represent dry years. Over the length of record there have been six major drought periods. The most recent drought began in 1998 and continues to the present time.

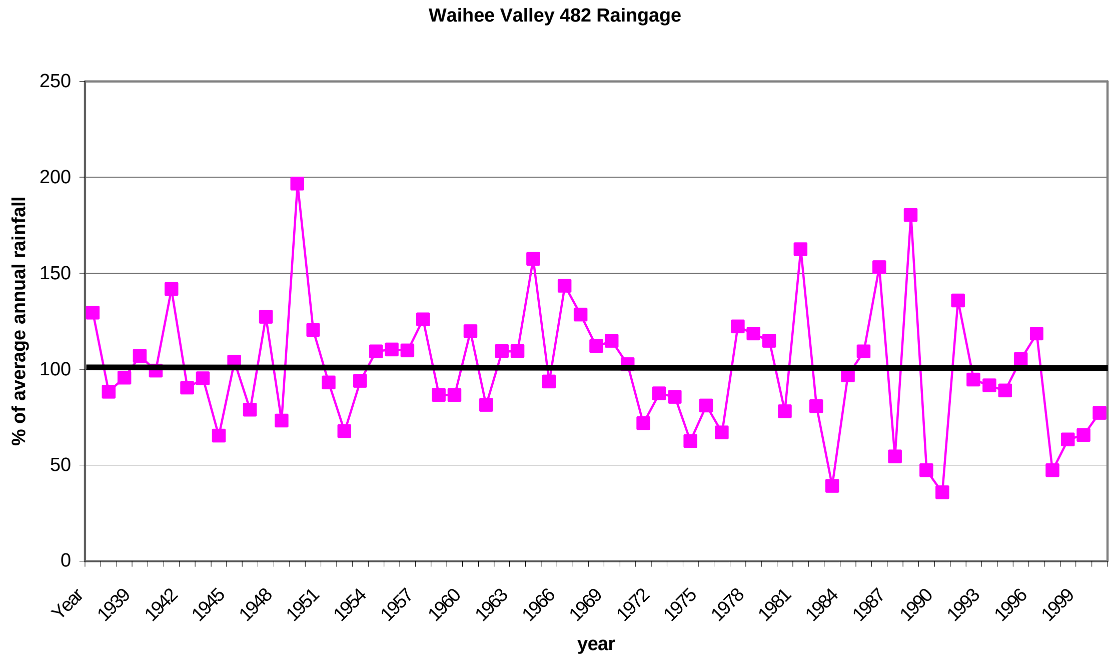

Figure 31. Annual rainfall as a percent of the mean, station no. 482 in Waihee Aquifer System

Table 8. Selected water balances for West Maui.
Note that these estimates refer to different areas and may not be directly comparable.

Region	Report	Area	Rainfall		Runoff		ET		Recharge			SY
		square miles	mgd	mgd/mi sq	mgd	% of rainfall	mgd	% of rainfall	mgd	% of rainfall	mgd/mi sq	mgd
Waihee Aquifer System	WRPP (Yuen and Assoc., 1990)	11.87	63	5.31	28	44%	23	37%	12	19%	1.01	8
Iao Aquifer	Shade (1997)	16.15	87	5.39	40	46%	18	21%	29	33%	1.80	
Lahaina District	Shade (1996) natural cond	96	330	3.44	95	29%	90	27%	145	44%	1.51	
Waihee Aquifer System	Mink (1995)	11.87	63	5.31	14.62	23%	23	37%	25.5	40%	2.15	
Wailuku	Takasaki (1978)	NA	370		175	47%	130	35%	65	18%		
District	State of Hawaii 1977 R54	60	265	4.42	53	20%	119	45%	93	35%	1.55	
Maalaea to Waihee	DLNR, 1970 (R38)	32.8	230	7.01	120	52%	50	22%	60	26%	1.83	
Iao	DLNR, 1970 (R38)	9.2	95	10.33	50	53%	10	11%	35	37%	3.80	
northwest Maui (Honokohau to Honokeana)	Belt Collins 1969 (R33)	NA	122		40	33%	53	43%	29	24%		
Iao Valley	Caskey 1968	6.02	53	8.80	39	74%	12	23%	2	4%	0.33	
West Maui	Stearns and Macdonald 1942 p 43	140	580	4.14					145	25%	1.04	
	Average (not weighted)					42%		29%		29%	1.75	

3.5.3. Fog Drip

In addition to rainfall, fog drip is a significant contributor to recharge in the Waihee Aquifer System. Fog drip is water vapor and precipitation that is caught by vegetation and then drips to the ground. Earlier fog drip studies on the islands of Hawaii and Lanai indicate that fog drip is a significant contributor to ground-water recharge on those islands (Anderson, 1984; Ekern 1978; Ekern, 1964; Mink, 1983). Water balance estimates in West Maui and the Waihee Aquifer System have not incorporated fog drip as a separate parameter.

Estimations of fog drip have not been made for the Waihee Aquifer System. Ekern (1978, p.3) notes that at an elevation of about 5,000 feet, fog drip is about 33 percent of rainfall. As the elevation increases above 5,000 feet the proportion of fog drip to rainfall also increases, though total precipitation is substantially less. The elevation of most ridges surrounding Waihee Valley are high but less than 5,000 feet. Therefore, fog drip in Waihee may be something less than 33 percent of rainfall.

3.5.4. Return Irrigation

Large-scale irrigation does not exist in Waihee. Therefore, return irrigation is negligible in the Waihee Aquifer System.

3.5.5. Runoff

Runoff is the average total stream flow for the aquifer system. It includes the direct runoff from rainfall and base-flow runoff derived from dike zone ground water. Runoff is estimated from existing stream flow data in the aquifer system and similar aquifer systems (Yuen and Assoc., 1990).

There are two perennial streams in the aquifer system: Waihee River and Makamakaole Stream (Yamanaga and Huxel, 1970). There are also several other streams with intermittent runoff. Presently, the U.S. Geological Survey maintains a streamgage on Waihee River. The USGS also collected stream flow data on Makamakaole Stream from 1939 to 1952. Table 9 summarizes stream discharge data and statistical parameters for Waihee River and Makamakaole Stream. Unfortunately, there are no reliable estimates of runoff from the remainder of the aquifer system. Kahakuloa Stream is on the northwest boundary of the aquifer system but is considered to be in the Kahakuloa Aquifer System.

Table 9. Waihee Aquifer System gaged streams

	Waihee Stream	Makamakaole Stream
station number	16614000	16617000
drainage area	4.20 square miles	0.40 square miles
elevation of gage (ft)	605	1500
period of record	11/1/1983 to 6/19/2002	7/1/1939 to 6/30/1952

Table 9. Waihee Aquifer System gaged streams (continued)		
Q average (mgd)	50.0	1.89
Q50, median (mgd)	34.9	1.10
Q90 (mgd)	24.6	0.59
Q min (mgd)	14.2	0.43
Q max (mgd)	749.7	56.87
average discharge per area (mgd/sq mile)	11.9	4.71

Although stream flow data is limited, several studies give estimates of total runoff from the Waihee Aquifer System or similar areas in West Maui (Table 8). The WRPP estimates average total runoff for the aquifer system as 50 in/yr over 11.87 square miles or 28 mgd.

The Waihee River data suggest that the 28 mgd estimate of total runoff may be too low (Table 9 streams data). The total streamflow from Waihee River alone at the 605-foot elevation averages 50 mgd. This is far more than the total estimated aquifer system runoff of 28 mgd. The Waihee River Valley has cut deeply into the dike complex. It is probably intercepting dike-impounded water that originates from other aquifer systems. This could account for the higher measured runoff. Figure 32 shows historical runoff information. Since 1982, measured stream discharge as the 12-MAV appears stable.

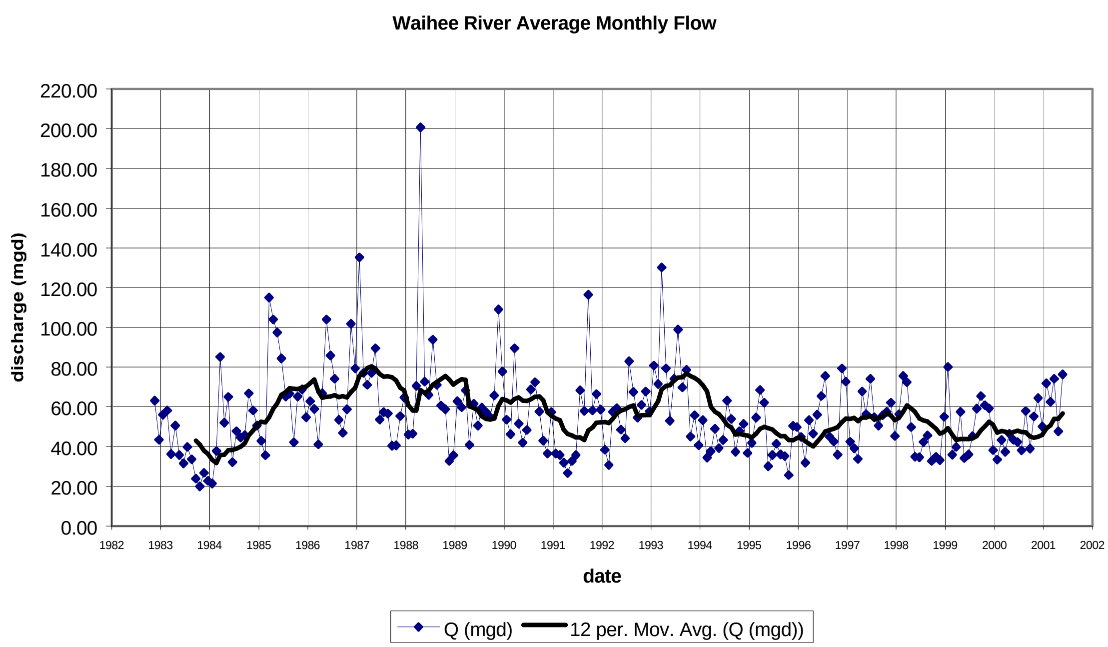

Figure 32. Waihee River average monthly flow at USGS gage 16612000

Makamakaole Stream originates from springs in clinker beds of the trachyte of the Honolua Formation (Stearns and Macdonald, 1942, p 201). These springs in the Honolua Formation are perched water springs that are not substantially affected by basal pumping. Runoff in Makamakaole Stream was stable during the period of record. A graph of monthly discharge in Makamakaole Stream from 1939 to 1952 is shown below (Figure 33).

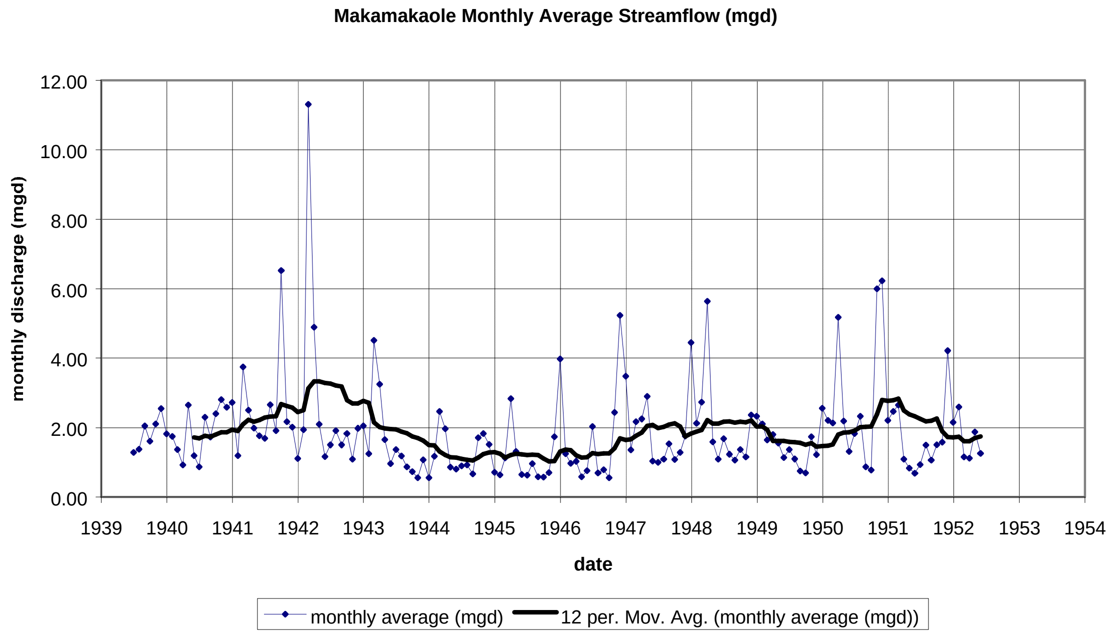

Figure 33. Makamakaole Stream average monthly flow at USGS gage 16617000

Waihee Tunnels 1 and 2 were constructed in 1909 to develop high-level water for irrigation purposes (Stearns and Macdonald, 1942; Yamanaga and Huxel, 1970). These tunnels discharge water into Waihee River that is later captured by ditch intakes. The current status or discharges of these tunnels are unknown due to their remote location (Garret Hew, personal communication, 2002). Stearns and Macdonald (1942) reported that streamflow at the intakes was not increased by the tunnels. Therefore, most of the water developed by the tunnels must have formerly discharged into the stream as springs along the stream below the tunnels and above the intakes. The net effect is these tunnels simply redirect spring flow along the reach of Waihee River and do not increase runoff.

Despite the unknown factors in the estimation of runoff, the WRPP (Yuen and Assoc., 1990) estimate of runoff as a percentage of total rainfall is consistent with other estimates of runoff in West Maui (Table 8. water balance table).

3.5.6. Evapotranspiration

Evapotranspiration is the surface and subsurface water released to the atmosphere through direct evaporation and by transpiration through plants (Todd, 1980 p 361). Evapotranspiration can be estimated from pan evaporation data. Evapotranspiration has been estimated in previous studies and results are tabulated in the water balance table (Table 8).

There is no known pan evaporation data from the Waihee Aquifer System. The nearest reported pan evaporation data found in State Report R74 (Ekern and Chang, 1985), come from evaporation pan stations, State Key No. 385, near Wailuku. Report R74 shows that adjusted annual evaporation near Kahului is 81 inches per year. Maximum pan evaporation in the Waihee System is about 70 inches/year (R74). There is no pan evaporation data from central West Maui, but if we extrapolate from other mountainous areas in Hawaii below the trade wind inversion we can estimate the minimum pan evaporation at about 20 to 30 inches/year.

Pan evaporation will generally be greater than actual ET because it is based upon an unlimited supply of water to evaporate. The WRRP estimate of average actual evapotranspiration for the entire system is 40 in/yr, or 23 mgd (Yuen and Assoc., 1990). This is a relatively high value for evapotranspiration compared to other past studies and actual evaporation measurements, which would result in less recharge.

3.5.7. Ground-Water Recharge

The primary objective in calculating the water balance for Waihee is to determine recharge. Ground-water recharge is that amount of water, applied in any manner to the ground surface (i.e., natural or irrigation return), which infiltrates into and becomes part of an aquifer. Recharge to the system takes place over both the high-level, basal, and caprock aquifers. This report is concerned with recharge to the dike and basal water bodies. This report uses the water balance method in determining recharge, as illustrated in Figure 5 and summarized in Table 8.

The WRPP (Yuen and Assoc., 1990) estimated mean recharge in the Waihee Aquifer System to be 12 mgd. This estimate of recharge is 19 percent of total rainfall. This is conservative when compared to the average recharge estimate of 29 percent of total rainfall by other researchers (Table 8). CWRM staff believes that we should continue to use conservative estimates of recharge until the size of the resource is verified by long term pumping experience.

3.5.8. Ground-Water Pumpage

There are 16 well within the Waihee Aquifer System (Table 10). Pumpage is primarily from MDWS wells (North Waihee 1 and 2, Kanoa 1 and 2,) and minor pumping from 4 private wells. Tunnel flows are intercepted spring flow in Waihee River, and therefore are not counted as pumpage.

Table 10. Waihee Aquifer System well list

Well	Well No.	owner/ user	type of well	date drilled	average pumpage 12 MAV (mgd)	Initial chloride (mg/L)	elevation at bottom of well (ft)	initial head (ft)	Initial temp (deg F)
North Waihee 1	5631-02	Maui DWS	municipal	1981	1.419	14	-105	9-10	
North Waihee 2	5631-03	Maui DWS	municipal	1981	1.424	15	-105	9-10	
Kanoa 1	5731-02	Maui DWS	municipal	1999	0.752	25	-51	9.32	69
Kanoa 2	5731-04	Maui DWS	municipal	2000	1.245	25	-52		
Kanoa Monitor TH-1	5731-05	USGS	monitor		0			12.4	
Kupa'a	5731-03	Maui DWS	inactive municipal	1999	0	25	-50	6.75	71
Kahakuloa Acres	5832-03	Island Shores	irrigation	1994	0.015	29	-20	6.84	70
Wailena	5832-02	Island Shores	irrigation	1985	standby to Kahakuloa	28		6.4	71
Waihee Marino 1	5631-05	Marino D	domestic	1991	0.072 (1)	25	-56	8.3	70
Waihee Marino 2	5631-06	Marino D	domestic	1991	0.072 (1)	25	-50	7.5	70
Mendes	5731-01	Medes E	not in use		0				
Obyrne	5832-01	Obyrne	domestic		unknown				
Waihee	5631-04	Marino-Lamanti	domestic	1985	very little (1 home)		9		
Waihee Tunnel 1	5434-01	HC & S	flowing tunnel	1909	4.6 (2)		1625 (3)		
Waihee Tunnel 2	5434-02	HC & S	flowing tunnel	1909	1.0 (2)		1650 (3)		

(1) pump size
(2) tunnel flow measured August 1933 (Stearns and Macdonald, 1942 p 213)
(3) portal elevation

Large-scale pumpage began in Waihee in 1997. Currently, the 12-MAV is just under 5 mgd. Figure 34 illustrates the historical pumpage data in the Waihee Aquifer System. The primary ground-water user is MDWS and pumpage is concentrated in the southern part of the aquifer system. The MDWS is planning to drill a new well (Maluhia Well) 750 feet north of Makamakaole Stream (C. Takumi Engineering, letter to CWRM dated August 30, 2002). If successful, this well will take advantage of recharge in the northern part of the Waihee Aquifer System

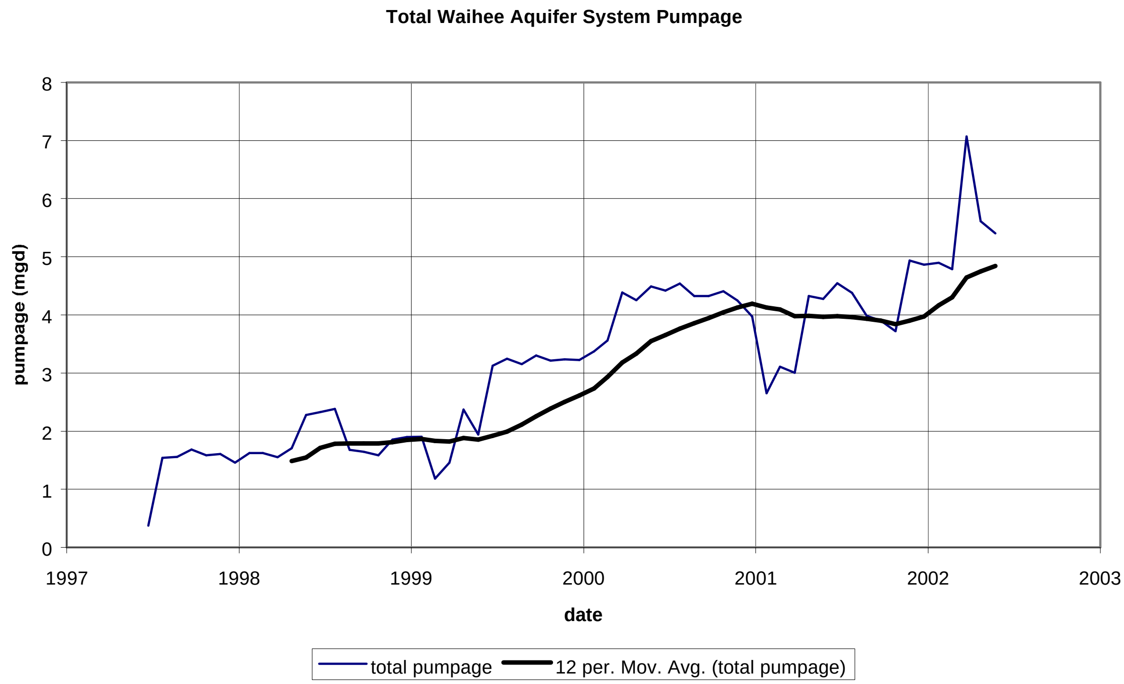

Figure 34. Total historical Waihee Aquifer System pumpage

3.5.9. <u>Water Levels</u>

The collection of water-level data in the Waihee Aquifer System began in 1981. Regular water-level collection did not begin until 1988.

Water levels within a basal aquifer in steady-state are described by the Ghyben-Herzberg principle. This principle recognizes the 1:40 ratio where fresh water (at an average specific gravity of 1.000) floats on salt water (at an average specific gravity of 1.025). For every foot of fresh water above mean sea level (MSL), the distance to the mid-point of the transition zone extends approximately 40 feet below MSL under steady-state. Under natural pre-development conditions, it is assumed that the aquifer is in a steady-state condition. Therefore, water levels under natural pre-development conditions are governed by the Ghyben-Herzberg principle, geological boundaries, aquifer formation properties, recharge, and leakage. Coastal caprock formations are a geologic boundary that are less permeable than the basaltic formations and reduce leakage to the sea and, thus, generate relatively higher basal water levels and deeper fresh water lenses than areas with no caprock. The Waihee Aquifer System does not have a coastal caprock but the Honolua Formation behaves like a caprock because of its low permeability.

Water levels under developed, or pumping, conditions are governed by the Ghyben-Herzberg principle, geological boundaries, aquifer formation properties, recharge, leakage, and pumpage. However, in the short-term, pumpage is the primary governing factor that determines water-level elevations, not the transition zone mid-point elevation. Such a reaction is known as a cone of depression. Water levels are drawn down in a fashion that extends outward from the pumping well (see Figure 18). When pumping ceases, localized pumping stresses only found in the pumping well (i.e. turbulence losses, well bore storage, etc.) dissipate and the water level will rise to match the Ghyben-Herzberg principle in relation to the location of the transition zone mid-point. Likewise, in the vicinity of a pumping well, water levels will rise to match the Ghyben-Herzberg principle in relation to the location of the transition zone mid-point. This rise will begin to occur immediately after cessation of pumpage and continue over time at a slower rate.

The most important water-level data is the initial measurement made in 1981, where the first measured basal water level in the Waihee Aquifer System was 10± feet MSL (Mink, 1981) at North Waihee 1. This pre-development water level represents the initial steady-state water level at this point in the Waihee Aquifer System. Under this initial condition the thickness of the lens at North Waihee 1 should have been 400± feet taken to the mid-point of the transition zone (chloride concentration of 9,500 mg/L or 50 percent isochlor). This is the point used in estimating sustainable yield using RAM (WRPP, 1990).

Waihee water levels are also very sensitive to rainfall patterns. Like Iao, it appears that rainfall correlates strongly with observation well water levels in the Waihee Aquifer System. Figure 35 also provides an explanation for the correlation of water levels in the Waihee and Iao Aquifer Systems. Both aquifer systems are heavily influenced by regional rainfall. Rainfall patterns are essentially the same in both aquifer systems. However, pumpage patterns and spacing of wells in both aquifers are much different. When comparing rainfall, pumpage, and water-level response patterns, it seems very clear that water levels follow rainfall patterns much more closely than pumpage. The USGS also recognizes that the water levels are sensitive to rainfall (Meyer and Presley, 2001). The 1998-2001 drought explains the decline in water levels.

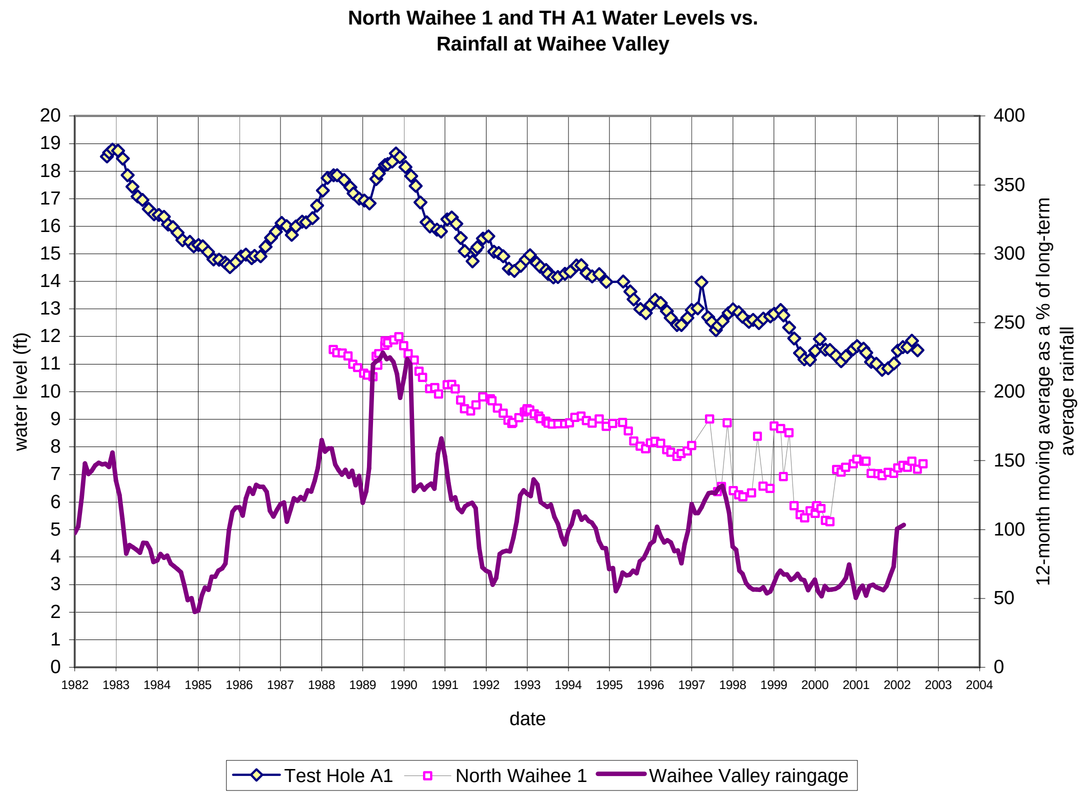

Figure 35. Water levels at North Waihee and TH A1 graphed with rainfall at Waihee Valley.

The water-level information presented in Figure 36 shows the reaction of water levels in the basal aquifer to pumping stresses over the past 13 years in both the Iao and Waihee Aquifer Systems. Water levels appeared to decline from about 11.5 feet to 8 feet from 1989 to 1997.

Development of the Waihee Aquifer basal ground-water changed the equilibrium conditions within the aquifer as pumpage reduced natural leakage by an equal amount. Pumpage will reduce the volume of the basal lens and lower the initial steady-state water level. As the head becomes lower, the leakage from the aquifer will decrease. Eventually, the head levels will reach a new equilibrium based upon the new pumping conditions.

From 1989 to 2002, average pumpage from the aquifer system increased from negligible to over 5 mgd. Municipal pumping started at the North Waihee Wells in July 1997. During this period, it can be seen that the maximum measured operating head levels at North Waihee Well 1 decreased from about 8 feet to 7 feet above MSL. This drop in head is partially

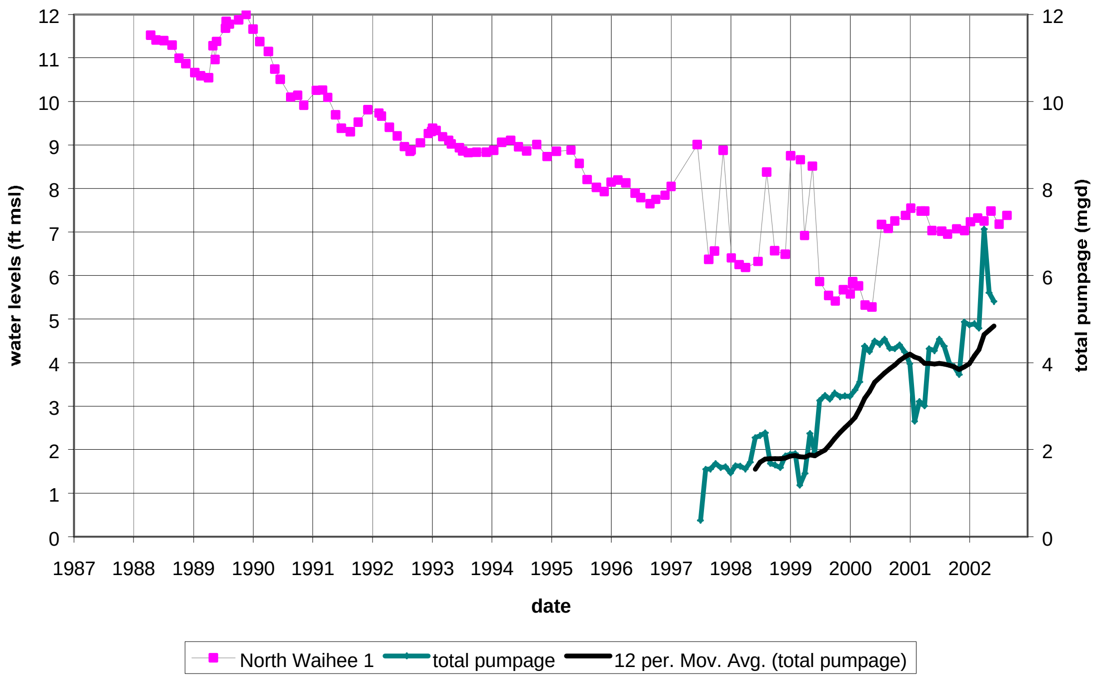

Figure 36. Water levels at North Waihee 1 and total aquifer system pumpage.

attributable to the fact that the well used for monitoring is a pumping well. The well is also at the center of the cone of depression caused by the North Waihee Wells' pumpage. Water levels have essentially been stable since July 2000 despite the fact that pumpage in the aquifer has increased. Analysis of Figures 35 and 36 suggests that water levels in Waihee have been more influenced by rainfall than the pumpage. However, correlation coefficient analyses results are not valid due to the short period of record and the close proximity of pumping.

The USGS has recently begun measuring water levels at an observation well near the Kanoa Wells. This well is also within the cone of depression of the Kanoa Wells, but its measurements are not influenced by drawdown in the pumping well. The water level before pumping at Kanoa Well was 7.81 feet (Mink, 1999). Currently the water level is about 7 ft. The water levels measured at Kanoa are essentially identical to the water levels at North Waihee.

The recovery of water levels towards steady-state conditions can be observed when aquifer pumping is temporarily shut off. In January 2000, wells in Waihee and Iao were briefly shut off to attempt to measure water-level recoveries. Mink (Mink and Yuen memorandum February 8, 2000), calculated that water levels at the North Waihee Wells in the Waihee Aquifer System would recover to their full equilibrium storage heads within three weeks.

3.5.10. Water Quality

3.5.10(a)Chlorides

The chloride ion concentration is a measure of salinity used to indicate the potential potability of the resource. U.S. EPA guidelines suggest that the 250 mg/L chloride concentration is a taste standard and should be the upper limit for water supply systems. This secondary contaminant limit is based on aesthetics, rather than health reasons, and is not mandatory. Normally, the counties' water supply purveyors further endeavor to keep the delivered supply at 160 mg/L or less. Additional factors influencing chloride concentrations within individual wells in basal aquifers, such as Waihee, include geology, hydrologic properties of the aquifer, and well infrastructure (such as well depth, pump capacity, pumping schedules, etc.) and produce observable long-term trends.

Chlorides differ depending on hydrogeologic conditions. Dike-impounded sources, such as the Waihee Valley Tunnels, have high water levels and no known evidence of contact with seawater, which results in low chloride concentrations. However, no data has been collected to confirm that salt water underlies high-level aquifers, which would require drilling a well thousands of feet deep. Basal sources are more susceptible to changes in chloride concentrations because the Ghyben-Herzberg lens floats on denser salt water and, therefore is in direct contact with salt water. The contact between fresh and salt water is not sharp but rather diffuse in a zone of mixing, also known as the transition zone (See Figure 4 showing cross section). These transitions zones vary in thickness from aquifer to aquifer.

Chlorides are also impacted by well infrastructure. Localized chloride increases can be due to upconing effects resulting from high pumpage rates of individual wells, a well's depth, and aquifer properties in the vicinity of the pumping station. In addition to localized upconing, well infrastructure can be affected by aquifer-wide shrinkage of the basal lens, which would increase chloride trends in all well sources. Deep wells, wells with large pump capacities, and wells closest to the ocean would be the first to experience higher chlorides**.**

Deep monitor wells help us distinguish between localized upconing and aquifer-wide hydrogeologic conditions affecting salinity. There is no deep monitor well in the Waihee Aquifer System.

Table 10 (see Ground-Water Pumpage Section) lists the initial chloride concentrations when current active wells in Waihee Aquifer were first drilled and tested. Chloride levels in the North Waihee Well field have remained level since production began in July 1997. Chloride levels in the Kanoa Well field have increased steadily since production began in March 2000. The chloride levels in Kanoa are still well within acceptable levels. The water in all four wells has relatively low chloride concentrations for a basal water source (see Figure 37). Despite the relatively low chloride concentrations, we recommend that the upward trend of chloride in the Kanoa Wells be monitored.

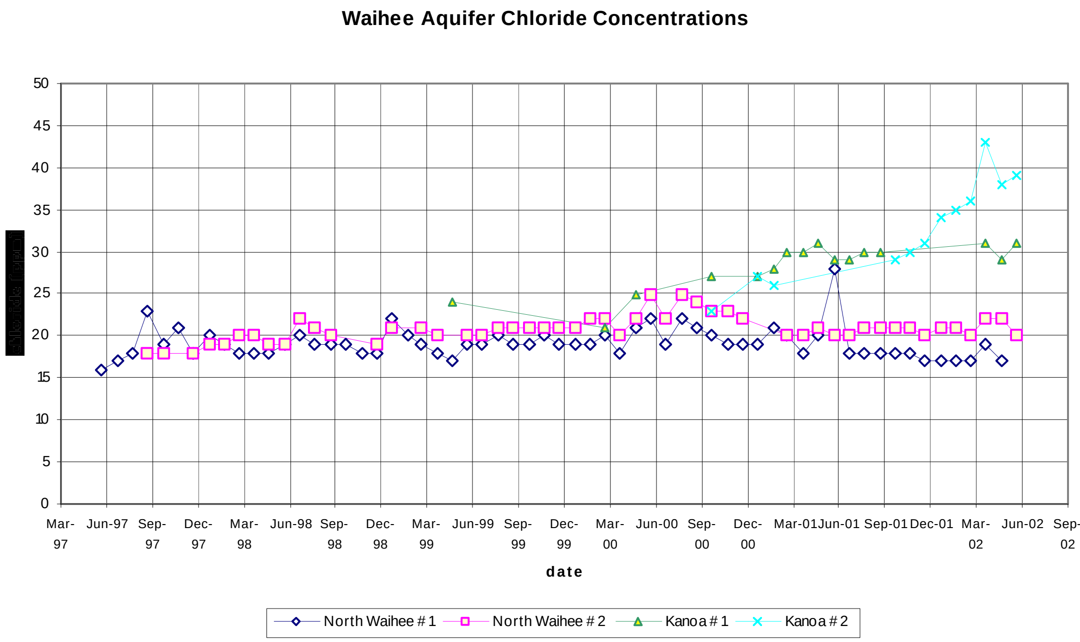

Figure 37. Graph of chloride concentrations at the North Waihee and Kanoa Well fields

3.5.10(b) Temperature

Visher and Mink (1964, p. 122) report that the temperature of water recharging the Koolau aquifer averages 67.5 °F, while ground-water temperatures in Honolulu average about 70 °F. Water temperatures in the North Waihee and Kanoa Wells are about 70 °F. There is no vertical profiling of temperature in the Waihee Aquifer System, because a deep monitor well has yet to be drilled in the area.

3.5.10(c) Contaminants

According to the Department of Health, Safe Drinking Water Branch, there have been no detectable organic or inorganic contaminants found in Waihee Aquifer System potable water wells.

3.5.11. Sustainable Yield

Under the State Water Code, sustainable yield is defined as follows:

HRS §174C-3 - *"Sustainable yield means the maximum rate at which water may be withdrawn from a water source without impairing the utility or quality of the water source as determined by the commission."*

In determining sustainable yields, the Commission distinguishes between optimal potential development of an aquifer and the man-made limitation on withdrawals imposed by existing infrastructure. Under the WRPP, sustainable yields are derived by the RAM and address the optimal potential development perspective for planning and managing purposes. RAM was never intended to address constraints imposed by actual infrastructure perspective. To address the infrastructure perspective, a regional numerical model is required. The Commission has revised sustainable yields when 'acceptable' numerical models have been developed **and** there has been competition amongst large users (e.g. Ewa-Kunia, Waipahu-Waiawa, and Kualapuu Aquifer Systems). There has been another numerical model developed to address infrastructure constraints to sustainable yield (e.g. Lanai, Ewa Caprock) but the Commission did not revise the WRPP sustainable yields. In the case of Lanai sustainable yield was not revised due to the lack of competition between large users. In the case of the Ewa Caprock, Commission determined to use chloride limits to non-potable individual wells to manage and protect the aquifer. Therefore, given the facts that the MDWS is the sole large user in Waihee and no numerical model exists for Waihee, it would seem more appropriate to use the optimal potential development perspective at this time. However, the county is pursuing the development of a 4.5-year $1 million dollar numerical modeling project, that includes Iao and Waihee, to be done by the USGS (June 28,2002 letter from USGS to MDWS). Once this project is done, the Commission may then consider revising Iao aquifer sustainable yield from the infrastructure perspective.

The current official CWRM estimate for sustainable yield is 8 mgd, as adopted through the WRPP. The official recharge estimate is 12 mgd. Ultimately, actual field data will be needed verify that pumping at 8 mgd is not endangering the aquifer. Currently, the limited data suggest that the current pumpage at 5 mgd will not endanger the aquifer. The current 12-MAV is 4.8 mgd and is 60 percent of sustainable yield.

Given the past methodologies and estimates for sustainable yield shown in Table 10 it appears that 8 mgd is reasonable. The CWRM estimate of sustainable yield uses 19 percent of total rainfall. This is conservative compared to other estimates of sustainable yield in West Maui. Presently, this estimate has been approved by the CWRM and adopted by Maui County for planning purposes. The reaction of the basal aquifer system to present pumping conditions and stresses seems to indicate that the aquifer is in no danger at this time.

3.6. Future Development and Projected Water Use

Figure 38 shows that the Iao and Waihee Aquifer Systems are the sole sources for the potable municipal Central Maui Service Area (CMSA), which sprawls from Waihee and Wailuku to Kahului and Paia, to Kihei, Wailea, and Makena. The map is a composite of Maui aquifer systems and the CMSA infrastructure. The Iao and Waihee Aquifers Systems are shaded, while the service area is marked by a dashed line.

Potable water delivered through this municipal system serves both potable and non-potable needs. Figure 39 is a schematic of the main potable CMSA. There is another segment of demand for irrigation water that is met through effluent reuse, administered by the County of Maui, Public Works, and individual well systems. However, upon asking the County for a delivery breakdown of potable vs. non-potable needs, the County indicated they could not differentiate between these major categories of use.

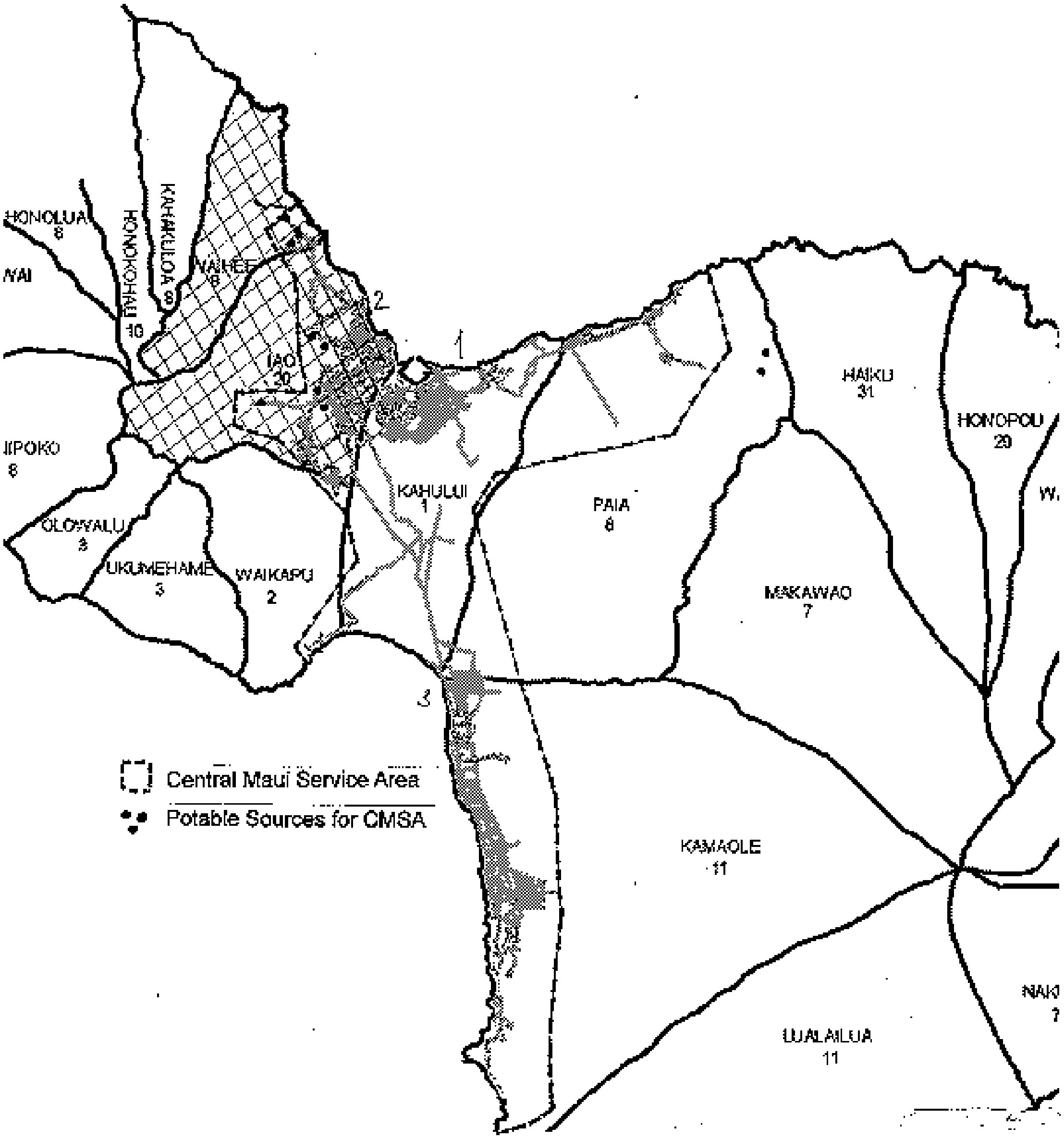

Figure 38. Central Maui Water (Wailuku) System

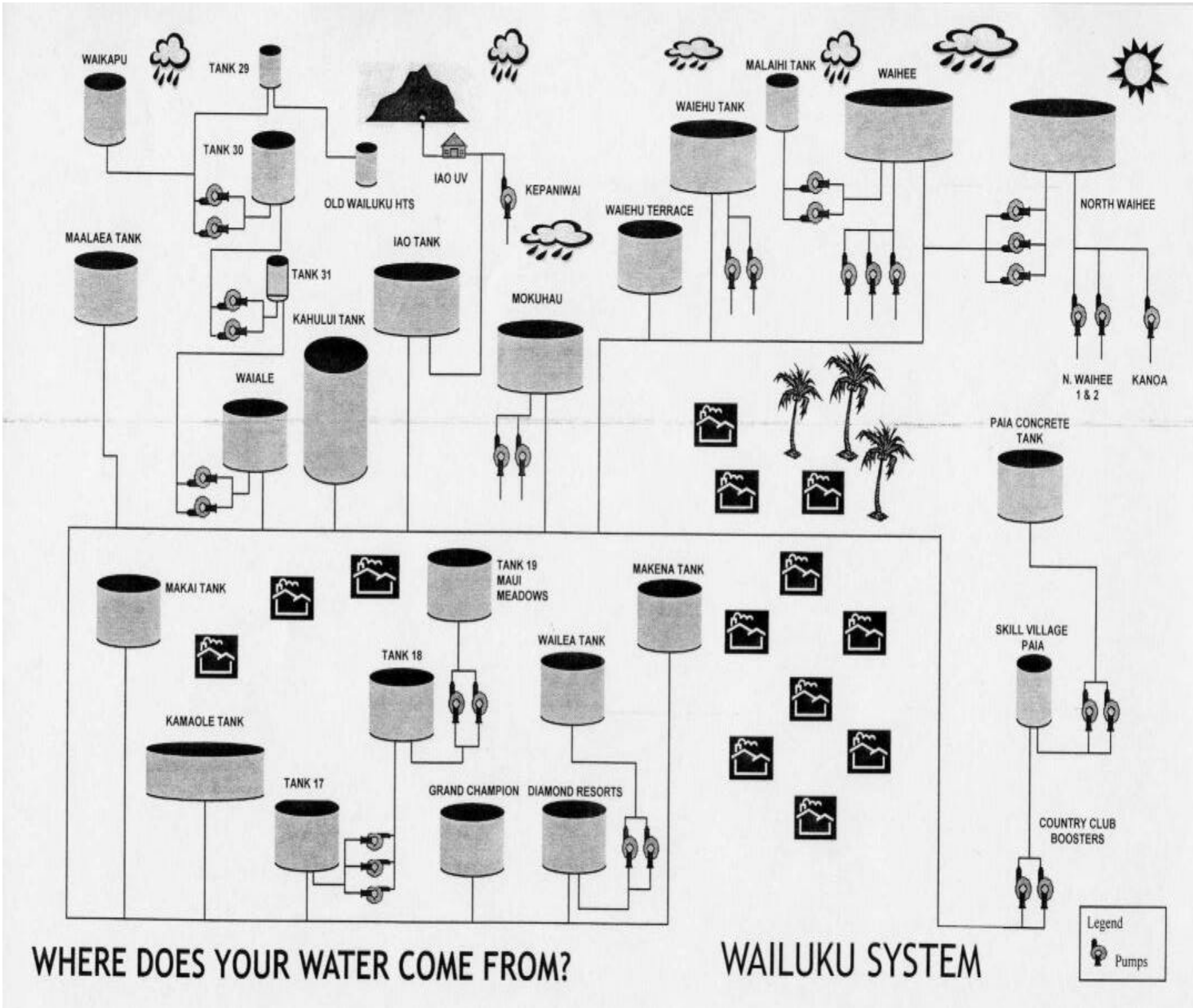

Figure 39. Central Maui Water (Wailuku) System
(Source: Maui Department of Water Supply web page, http://mauiwater.org/)

3.6.1. Growth of Demand served by Iao and Waihee.

3.6.1(a) Current Demands

Total water use in the CMSA increased about 19 percent from 1994 to 2001 (from 18.318 mgd to 21.762 mgd, according to MDWS figures). Despite an uneven sequence of growth in three major areas, after eight years the distribution between three different areas has remained essentially unchanged:

Waihee -Wailuku	19 %
Kahului-Spreckelsville	25
Kihei-Makena	56
	100 %

Total current 12-MAV (through June 2002) source production for the Central Maui Service Area is currently as follows:

Iao Aquifer Wells	16.084 mgd*	
Waihee Aquifer	4.840 mgd*	* counted against sustainable yield
Iao Tunnel	1.116 mgd	
Total	22.040 mgd	

The difference between 21.762 mgd reported by the County in 2001 and the 22.040 mgd reported by CWRM in 2001 reflects a significant reduction in Iao pumpage due to new pumpage from two new wells in Waihee.

Unaccounted for water represents system losses and cannot be measured directly. The losses are determined by the amount of water supplied to all the customers (metered at the property line) divided by the amount of water metered at the sources. MDWS estimates the unaccounted for water in the CMSA is 5 to 6 percent (Kraftsow, 2002, personal communication).

3.6.1(b) Projected Demands

Projected year 2010 water production requirements for the CMSA were estimated at 31.1 mgd in the 1990 Maui County Water Use and Development Plan (WUDP). The current ultimate demand, based on current plans, is 29.19 mgd. Current 2002 projections of potential new use from discussions with Maui County since initiation of this designation proceeding are listed and compared with the 1990 WUDP and 1996 FOF values in Table 11 below:

Table 11. Total projected demand

Description	1990	'96 FOF mgd	2002 mgd
Existing water commitments[1] (Water System Development Fee Rule)		0.410	0.411
Approved building permits w/o commitments		0.480	NA
Pending and approved building permits[2]		0.476	6.736
Central Maui Joint Venture (contractual obligation)		6.750 to 7	NA[3]
Additional demand total		8.116 to 8.366	7.147
12 –MAV pumpage for CMSA for calendar year	15.4	20.35	22.040
Total projected use	31.1[4]	28.5 to 28.7	29.2

***Notes**:*

1) *Source: Maui DWS: Existing water commitments are a moving number, month by month, as commitments are made and projects are connected and taken off this list.*
2) *Source: Maui DWS: The 2002 figure for pending projects simplifies "projects without commitments" to include projects with approved permits, and those with approval still pending; and it includes many projects which were part of the Central Maui Joint Venture (JV) commitment. The list used to estimate amounts omits 20 to 30 very small projects totaling less than 0.25 mgd.*
3) *The amount of this commitment is now disputed in court. Because the projects on the list have such a long time frame (some have been on hold since the 1980's), any additional amount following a resolution of the JV commitment are commensurate with the total build out by 2020.*
4) *Source: County of Maui WUDP.*

The 1996 Findings of Fact reflected the County's estimates of new development in four categories and the County updated the 2002 values for these same categories as close as possible. These 1996 and 2002 projections do not have a specific time frame but may in fact be closer to a 2020 time frame, at which point many options for new sources should emerge. It would seem that total projected demands for the CMSA have increased by about 0.5± mgd since 1996.

Added to current use of 22.0± mgd, current projections thus reach 29.2± mgd. This is roughly 2 mgd less than that projected by the 1990 WUDP. Given current water sources in the Iao and Waihee Aquifer Systems, the projected demand exceeds the combined sustainable yield total of 28 mgd by 1.2± mgd.

3.6.2. Growth of CMSA Supply

Since the 1996 Commission decision not to designate Iao, there has been significant growth in the CMSA infrastructure. North Waihee Wells 1 and 2 (5631-02 and 03) were being brought on-line in 1997, and in 2000 the Kanoa Wells (5731-02 and 04) were put into service. These active sources provide an average of 5± mgd. Two additional wells (Waikapu Mauka

(5131-01) and Kupaa (5731-03)) have been drilled but are not in service at this time. MDWS also has plans to drill another well in Waihee (Maluhia, north of Makamakaole Stream).

The new Waikapu Mauka Well (5131-01) is scheduled to come on line shortly. This well is located in the Iao Aquifer System but at its southern boundary, and will supply up to 2 mgd. Its purpose is not to increase pumpage but rather to redistribute current pumpage within Iao.

It is unknown when the new Kupaa Well (5731-03) will come on line. It has been drilled in the Waihee Aquifer System south of Makamakaole Stream and its purpose is to distribute existing pumpage within the Waihee Aquifer System.

Outside Iao and Waihee

The East Maui Water Development Plan (EMWDP) shows the intent to supply the CMSA from sources in the Haiku Aquifer System (Aquifer 60401). The sustainable yield for this aquifer is 29 mgd. The EMWDP will produce an average of 9.3 mgd from eight new wells. This amount should cover the current projected 1.2 mgd deficit for the CMSA and, presumably, newer developments in Haiku and or other areas serviced by the CMSA. The Maui WUDP is currently being updated and should provide better information on the projected demands in these other areas. In 1997, the EMWDP was stalled in court for lack of an adequate EIS. A Supplemental EIS has now been completed and must now be reviewed and cleared by the Court. Until the EMWDP moves forward, the demand on the Iao and Waihee Aquifer Systems will exceed their combined estimated sustainable yields by 1.2 mgd.

Although initially part of the EMWDP, Hamakuapoko Wells 1 and 2 in the Paia Aquifer System (Aquifer 60302 SY = 31 mgd) are currently used to supplement the Upcountry water system. These wells supply an additional 1.5 mgd.

Additionally, the Kihei-Makena Community Plan (1998) projects resident population growth for the area between 22,830 and 24,514 residents by 2010 as compared to the 1990 population of 15,365. The visitor population is not taken into account in these figures, but is estimated to be large. The plan states that water supply increases will be concurrent with planned growth, and supports the projected development of the Central and East Maui water systems. However, using County water demand standards of 600 gal/day per single family unit, and assuming 4 residents per unit, this population growth would translate to an increase of 1.25 mgd. This number cannot be reconciled with Table 11 above.

3.6.3. Iao Water Management Rule

On March 5, 1999, the Maui BWS approved the Iao Water Management Rule, Title 16, Chapter 9 of the Maui County Administrative Rule (See Appendix F). In general, this rule is intended to prevent over pumpage of the Iao Aquifer System and in a manner that seeks to prevent conditions that would meet some of the designation criteria set out under the Water Code.

In terms of implementing the rule, maximum absolute 3-MAV chloride limits have exceeded limits defined in the Rule on many occasions apparently without any declaration of such conditions. In 2001, Waiehu Heights 1 and Mokuhau 1 and 3, had exceeded the 200 mg/L, 3-MAV limit of the "Critical Low Ground Water Conditions", but there is no evidence of notification given to the public, the County Council, or the CWRM, nor follow-up actions as is required under §16-9-5. Therefore, this management rule has not been enforced.

3.7. County and Public Testimony

Testimony has been compiled through the petition, solicitation of comments, CWRM meetings, and public hearings as required under the designation process. Original comments are found in Appendices B and D and are summarized in Table 12 as follows:

Table 12. Summary of testimony

Sector	Name	Pos	Comment
Petitioner	James Williamson	Y	• Aquifer shown marked deterioration since 1997: rising chlorides, lower water levels • Iao and Waihe'e Aquifers have no physical boundary between them, are same aquifer, w/ SY 20 total • Iao Management Rule not being enforced • New development being approved w/o regard for water availability; should declare moratorium on new meters • Need new wells outside "Iao" – 3-4 mi North of Waihe'e Stream • Need deep monitor well in south part of aquifer • Planning & financing water development inadequate
County	Mayor Kimo Apana	N	• Reduced pumping in Iao Aquifer • Pumpage spread to Waihe'e, surface sources • Enactment of Iao Management Rule • Charter Commission considering structural change to empower BWS
County	Council		• No comments offered. Only questions asked of CWRM concerning hydrology and designation.
County	MDWS	N	• County has a responsibility to manage resources • DWS monitors water and chloride levels • Water levels reflect lengthy low-rainfall period • Waiehu well too deep, can be pumped less • Mokuhau well too deep, not pumped now • Central Maui Joint Venture agreement should not invite CWRM involvement • DWS will continue developing sources in Waihe'e Aquifer • Water level recovery after pumping shows similarity to long-term average • BWS enacted Iao Management Rule • DWS is primary aquifer user and can control management of use • BWS is convening special review of alternate sources • underlying question is whether designation would improve resource protection

Table 12. Summary of Testimony (continued)

Sector	Name	Pos	Comment
County	MDWS	N	• following solutions would be more effective than designation: – better coordination on land use permit approvals, observing DWS caveats about water availability and imposing reporting requirements on permittees – clarify county charter to give DWS jurisdiction over all water resources in county, not just under Board development – require county well permits (in addition to CWRM permits) to assure construction to county specs, proper reporting – improve coordination between "quantity" (CWRM) and "quality" (DOH) issues within DWS – initiative to fill gaps in information by temporary staff or grant funding – clarify discrepancies between published documents and operating knowledge/policy, e.g. Haiku SY=31 or 15? – Clarify CWRM support for county positions reserving water for municipal use, e.g. EMWDP – coordinate pumpage guidelines w/ CWRM, USGS & UH/WRRC – rely on community-based WUDP to resolve conflicts • current efforts at Iao: source development to spread pumpage within and outside Iao; land purchase of watershed lands; free distribution of low-flow fixtures; leak detection, pressure monitoring, etc. • CWRM would have to engage time-consuming water use permitting process
County	Board of Water Supply	N	• Reduced pumping from Iao • Collecting data, drilling new deep monitor well
	Michael Nobriga	N	• Drought has caused problem • Iao Management Rule sets automatic and mandatory actions • Board does not allow new development w/o providing necessary supply • Board pro-active in securing additional resources • Water Use and Development Plans will provide a clearer picture
Hydrologist	William Meyer	na	• Sustainable yield for Iao <20 mgd; cannot be realized with existing infrastructure • RAM model used to estimate SY under predicts water level declines, cannot represent spatial variables • Withdrawals from caprock should be counted against SY • Iao and Waihe'e connected; Waihe'e well configuration is sub optimal • CWRM should require "safe water levels", disallow "intrusion water levels" • WRPP does not specify optimum well spacing or depth guidelines, is insensitive to aquifer interconnectedness • WRPP does not commit CWRM to program of upgrading information and theoretical foundations
Hydrologist	John Mink	na	• Resource integrity should be determined by examining depth of lens, not water level above sea level; drawing conclusions about aquifer depth from localized water levels in pumping wells overestimates effect of pumpage • Critique of RAM model suffers from misunderstanding of storage head, ignoring salinity-depth curves, and willful ignoring of ordinary field observations; model accurately predicts empirical contraction. • Some connectedness of Iao and Waihe'e misses strong impedance and separate calculations based on groundwater-generating factors in Waihe'e; divide Waihe'e SY at Makamakaole

Table 12. Summary of Testimony (continued)

Sector	Name	Pos	Comment
Hydrologist	Gordon Tribble	na	• Regulatory level of sustainable yield should be distinguished from potential withdrawals of existing infrastructure • No single value for SY – dependent on distribution of pumpage, dynamic ground-water flow, and climatic change • RAM model ignore variability • Interconnectedness of aquifers means pumpage from one aquifer influences another • Focus should be on how to determine best yield from aquifers
			•
Public	Warren Suzuki	N	• reduced pumping rate • spreading pumping locations
Public	Don Fujimoto	N	• DWS the only user, has reduced pumping • intervention adds to bureaucracy • petition is by anti-growth activists to stop development
Public	Bobbie Becker & Jace Hobbs	Y	• dropping water levels • questions about recharge, aquifer boundaries, drought effect
Public	Barbara & Michael Reed Gach	Y	• want responsible planning; Kihei development beyond infrastructure capacity
Public	Randy Ching	Y	• no one knows how much is there, is being withdrawn, or how quickly it's recharged
Public	Andrea & Christopher Dean	Y	• no consensus on amount in the aquifer, amount used
Public	Hugh Starr	Y	• professionals record deterioration
Public	Isaac Harp	Y	• poor condition of supply • developers lobby for increased allocation
Public	Elaine Wender	Y	• aquifers may already have suffered permanent damage
Public	Maile Lu'uwai	Y	• escalating development • need to protect resource
Public	Kapua Sproat	Y	• "Please consider (Maui News article) Makena Rezoning Decision Delayed (02 Feb 02) • Iao is at its limit
Public	Jeffrey B. Parker	Y	• county agencies are mired in "develop – no matter what the costs" mentality, • continue to approve projects w/o regard for impacts
Public	Steve Slater	Y	• lost money because denied meter, but large landowners have no problem getting meters
Public	Jesse Slater	Y	• too much water going to big developers, disregarding needs of community
Public	Rebecca & Godwin Pelissero	Y	• with spiraling growth, we need to find out if there's enough water
Public	Roy Smith & Diana Dahl	Y	• development is competing w/ farming; we need a study to determine if there's enough water
Public	Martha E. Martin	Y	• development proceeds w/o good planning to manage water

			• we lack info on aquifer boundaries, recharge, the amount of withdrawals

Table 12. Summary of Testimony (continued)

Sector	Name	Pos	Comment
Public	Stefano Segre	Y	• with spiraling growth, is there enough water?
Public	Greg & Masako Cordray Westcott	Y	• rising saltwater levels
Public	Daniel Grantham	Y	• Sierra Club supports • long history of dependence on Iao, and overestimating its SY • declining water levels, rising salinity • on probation since 1997 • conditions meet several criteria • overpumping continues despite deterioration • we fail to account for private pumping in Iao, Waihe'e, Kahului
Public	Christina Hemming	Y	• USGS Exhibit 10 (14 Nov 01) says amount of long-term pumping depends on several factors: distribution of • pumpage, dynamic ground-water flow, climatic variability, current values based on model not addressing these • MBWS does not have authority to manage – just a utility to supply water • all criteria met • hotel/vacation rentals use disproportionate amounts (spa examples) • West Maui taro growers have lost water
Public	Lucienne de Naie	Y	• Ka Wai Ola project updates info • CWRM should also look at Kahului withdrawals: institutional – parks, assisted living, homeless shelter • some not on CWRM's database are sending in reports • Ka Hale Ola told (?) they could get permit because not in Iao, but boundary says they are • Iao withdrawals could affect Kanaha Pond • Iao appears to be connected to Waihe'e, Kahului, and Waikapu • too much poor research and piecemeal planning
Public	Megan Powers	Y	• paid-off politicians and untruthful analysis have led to overcommitment of water for development • next area to be overused could be East Maui, where streams are already dry, people have no access to water
Public	Chris Baz	Y	• continuing growth, but enough water?
Public	Terry Reim	Y	• Maui Tomorrow's Ka Wai Ola project updates database; not all users counted
Public	David Leece, Anne Pierce, Astrid Watanabe, Yolanta Marché Rob Story Jacob and Mary Anne Doane Mau	Y	• No specific comment

In addition to government agencies there were 42 individual testimonies submitted. The majority of interested public testifiers support designation. It is interesting to note that the Maui County Council has not submitted comments to date but instead has only asked questions about the hydrology and designation process.

3.8. Criteria For Designation

Chapter 174C, HRS, presents a listing of criteria that the CWRM must consider in determining the designation of a ground-water management area. These criteria are listed in Table 10.

Table 10. Ground-Water designation criteria

1. ***[§174C-44(1)]*** *Whether an increase in water use or authorized planned use may cause the maximum rate of withdrawal from the ground-water source to reach ninety percent of the sustainable yield of the proposed water management area;*

2. ***[§174C-44(2)]*** *There is an actual or threatened water quality degradation as determined by the department of health;*

3. ***[§174C-44(3)]*** *Whether regulation is necessary to preserve the diminishing ground-water supply for future needs, as evidenced by excessively declining ground-water levels;*

4. ***[§174C-44(4)]*** *Whether rates, times, spatial patterns, or depths of existing withdrawals of ground water are endangering the stability or optimum development of the ground-water body due to upconing or encroachment of salt water;*

5. ***[§174C-44(5)]*** *Whether the chloride contents of existing wells are increasing to levels which materially reduce the value of their existing uses;*

6. ***[§174C-44(6)]*** *Whether excessive preventable waste is occurring;*

7. ***[§174C-44(7)]*** *Serious disputes respecting the use of ground-water resources are occurring; or*

8. ***[§174C-44(8)]*** *Whether water development projects that have received any federal, state, or county approval may result, in the opinion of the CWRM, in one of the above conditions*.

Each criterion is assessed in light of the existing data and analyses as follows:

3.8.1. Iao Aquifer System Designation Criteria

CRITERION 1.

Whether an increase in water use or authorized planned use may cause the maximum rate of withdrawal from the ground-water source to reach ninety percent of the sustainable yield of the proposed water management area.

Discussion

In the past, MDWS has exceeded 90 percent of sustainable yield. Presently, water use is 80 percent of sustainable yield. The projected additional demand from the CMSA of 7.147 mgd is assumed to meet the definition of authorized planned use. Therefore, it may be necessary to pump Iao at 90 percent of sustainable yield or greater, if other alternative sources outside of the Iao and Waihee Aquifer Systems do not augment the CMSA.

Conclusion: **CRITERION 1 MET**

CRITERION 2.

There is an actual or threatened water quality degradation as determined by the Department of Health.

Discussion

No evidence has been presented by the Department of Health, Safe Drinking Water Branch, during the preparation of these findings of fact that indicates this criterion has been met at this time.

Conclusion: **CRITERION 2 NOT MET**

CRITERION 3.

Whether regulation is necessary to preserve the diminishing ground-water supply for future needs, as evidenced by excessively declining ground-water levels.

Discussion

Since the last known peak in 1982, water levels have declined significantly. However, this decline is not excessive for the following reasons:

1. Water levels have been stable for the past three years despite drought conditions;
2. Transition zone behavior indicates that the overall aquifer water levels are of concern but are not declining excessively aquifer-wide;

3. Pumpage and water-level data are concentrated north of Iao stream and ignores the southern portions of the aquifer. The new Iao Deep Monitor Well will help to determine if aquifer water levels are satisfactory.

Conclusion: **CRITERION 3 NOT MET**

CRITERION 4.

Whether rates, times, spatial patterns, or depths of existing withdrawals of ground water are endangering the stability or optimum development of the ground-water body due to upconing or encroachment of salt water.

Discussion

Evidence presented indicates this criterion is met at this time.

Under present withdrawal rates, depths and spatial patterns, water-level and chloride data indicate there is an upconing problem at the Mokuhau and Waiehu Heights well fields. It is no coincidence that the upconing occurs at these sites as they are the deepest, have the largest pumps, and are not spread out within the well fields. These may continue to endanger optimum development of Iao due to salt water encroachment unless modifications to these sources are made.

Conclusion: **CRITERION 4 MET**

CRITERION 5.

Whether the chloride contents of existing wells are increasing to levels which materially reduce the value of their existing uses.

Discussion

There have been significant increases in chloride concentrations in Mokuhau and Waiehu Heights Wells. Mokuhau 2 is the only well that is exceeding the EPA 250 mg/L guideline. This well has been taken out of service. Chloride levels in other wells are rising but are within the EPA guidelines.

Recent management efforts by MDWS have occurred in an attempt to ease the chloride concerns before a significant number of sources reach levels that met this criterion. These efforts include:

1. Reduction of pumpage at Mokuhau;
2. Reduction of overall Iao pumpage;
3. Maui BWS approval of Iao Water Management Rule.

Although the first two actions have occurred, chloride limits have been exceeded under the MDWS Iao Water Management Rule and enforcement actions have not been implemented.

However, recent declines in chloride concentration in sensitive wells show some improvement since early 2001. Ultimately chlorides are still acceptably below EPA guidelines that help define the utility of existing sources.

Conclusion: **CRITERION 5 NOT MET**

CRITERION 6. **Whether excessive preventable waste is occurring.**

Discussion

At this time, there is no evidence that there has been excessive waste.

Conclusion: **CRITERION 6 NOT MET**

CRITERION 7. **Serious disputes respecting the use of ground-water resources are occurring.**

Discussion

Since nearly all the water developed from the Iao Aquifer System is by MDWS, actual serious disputes between existing water users are not occurring. However, the Maui Meadows petitioner has raised the issue that the sustainable yield is an inaccurate portrayal of ground-water conditions. The current sustainable yield based on optimum development is still considered a reasonable estimate at this time. Also, this dispute is more about Iao hydrology than between actual or planned end use of ground water

Disputes regarding land use issues are not germane for CWRM. The CWRM has no jurisdiction on land use approvals that are under the purview of the County of Maui and the State Land Use Commission.

Conclusion: **CRITERION 7 NOT MET**

CRITERION 8.

Whether water development projects that have received any federal, state, or county approval may result, in the opinion of the CWRM, in one of the above conditions.

Discussion

Future water development projects in Iao that have recently received some sort of approval from government agencies are the Waikapu Mauka and Iao Deep Monitor wells. The Waikapu Mauka Well will spread the pumpage south of Iao Stream, but will not increase total overall pumpage for the aquifer. The planned Iao Deep Monitor well will monitor conditions in the transition zone south of Iao Stream. Both these wells should actually help avoid any one of the above designation criteria.

Conclusion: **CRITERION 8 NOT MET**

3.8.2. Waihee Aquifer System Designation Criteria

CRITERION 1.

Whether an increase in water use or authorized planned use may cause the maximum rate of withdrawal from the ground-water source to reach ninety percent of the sustainable yield of the proposed water management area.

Discussion

Use of the Waihee Aquifer System is only 62 percent of the sustainable yield. The projected additional demand for the CMSA of 7.147 mgd is assumed to meet the definition of authorized planned use. Therefore, it may be necessary to pump Waihee at 90 percent of sustainable yield or greater, if other alternative sources outside of the Iao and Waihee Aquifer Systems do not augment the CMSA.

Conclusion: **CRITERION 1 MET**

CRITERION 2.

There is an actual or threatened water quality degradation as determined by the Department of Health.

Discussion

No evidence has been presented by the Department of Health, Safe Drinking Water Branch, during the preparation of these findings of fact that indicates this criterion has been met at this time.

Conclusion: **CRITERION 2 NOT MET**

CRITERION 3.

Whether regulation is necessary to preserve the diminishing ground-water supply for future needs, as evidenced by excessively declining ground-water levels.

Discussion

Water levels have declined since 1989 but not excessively and seem more related to rainfall patterns than pumpage. Ground-water levels have been stable since 2000.

Conclusion: **CRITERION 3 NOT MET**

CRITERION 4.

Whether rates, times, spatial patterns, or depths of existing withdrawals of ground water are endangering the stability or optimum development of the ground-water body due to upconing or encroachment of salt water.

Discussion

Present withdrawal rates, depths and spatial patterns, water-level and chloride behavior show there is no upconing problem at this time. However, a proper deep monitor well would provide data to further verify this conclusion.

Conclusion: **CRITERION 4 NOT MET**

CRITERION 5.

Whether the chloride contents of existing wells are increasing to levels which materially reduce the value of their existing uses.

Discussion

Chloride concentrations in Waihee Aquifer System sources are well within acceptable limits.

Conclusion: **CRITERION 5 NOT MET**

CRITERION 6. **Whether excessive preventable waste is occurring.**

Discussion

At this time, there is no evidence that this criterion has been met.

Conclusion: **CRITERION 6 NOT MET**

CRITERION 7. **Serious disputes respecting the use of ground-water resources are occurring.**

Discussion

Since nearly all the water developed from the Waihee Aquifer System is by MDWS, actual serious disputes between existing water users are not occurring. However, the Maui Meadows petitioner has raised the issue that the sustainable yield is an inaccurate portrayal of ground-water conditions. The current sustainable yield based on optimum development is still considered a reasonable estimate at this time. Also, this dispute is more about Waihee hydrology than between actual or planned end use of ground water.

Disputes regarding land use issues are not germane for CWRM. The CWRM has no jurisdiction on land use approvals that are under the purview of the County of Maui and the State Land Use Commission.

Conclusion: **CRITERION 7 NOT MET**

CRITERION 8. **Whether water development projects that have received any federal, state, or county approval may result, in the opinion of the CWRM, in one of the above conditions.**

Discussion

Future water development projects in Waihee that have recently received some sort of approval from government agencies are the Kupaa and Maluhia wells. Both these well locations spread pumpage north within the aquifer and should actually help avoid any one of the above designation criteria.

Conclusion: **CRITERION 8 NOT MET**

4. <u>CONCLUSION</u>

At this time, the information available indicates that the Iao Aquifer System meets criterion §174C-44(1), and (4) while the Waihee Aquifer System meets criterion §174C-44(1) only under the State Water Code concerning designation of ground-water management areas. These criteria are:

1. ***[§174C-44(1)]*** *Whether an increase in water use or authorized planned use may cause the maximum rate of withdrawal from the ground-water source to reach ninety percent of the sustainable yield of the proposed water management area;*

2. ***[§174C-44(4)]*** *Whether rates, times, spatial patterns, or depths of existing withdrawals of ground water are endangering the stability or optimum development of the ground-water body due to upconing or encroachment of salt water.*

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